Evaluating the EU Carbon Border Adjustment Mechanism with a Quantitative Trade Model*

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We analyze the economic and environmental impacts of the European Carbon Border Adjustment Mechanism (CBAM) using a multi-country, multi-sector general equilibrium model with input-output linkages. We quantify the general equilibrium responses of trade flows, welfare, and emissions. To our knowledge, we developed the first quantitative trade model that jointly endogenizes both the Emissions Trading System (ETS) allowance and the CBAM prices. We find that CBAM marginally increases EU Gross National Expenditure (GNE) and shifts trade toward more domestic and cleaner production. Emissions embodied in direct EU imports fall by 4.8%, and by 3% when including indirect emissions – underscoring the importance of accounting for production networks in evaluating policy outcomes.

JEL codes: F13; F64; F42; Q51; Q56

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1. INTRODUCTION

Despite decades of international climate efforts, greenhouse gas (GHG) emissions have continued to rise throughout the 21st century (Dhakal et al., 2022). Since 2005, a cornerstone of the European Union's climate policy has been the Emission Trading System (ETS), a market-based mechanism that has proven effective in reducing emissions. While the ETS covers the EU as well as Norway, Iceland, and Liechtenstein through the European Economic Area agreement, its scope remains geographically limited. This creates a risk of carbon leakage — where emissions-intensive production is relocated to countries with laxer climate regulations. To counter this, the EU introduced the Carbon Border Adjustment Mechanism (CBAM), which seeks to equalize the carbon cost between imported and domestically produced goods. Since 2023, the CBAM has been in a transitional phase, requiring firms in selected sectors to report the embodied emissions of their imports without financial obligations. Starting in 2026, importers will be required to purchase CBAM certificates corresponding to the carbon content of covered goods, which should reduce incentives to shift emissions abroad and strengthen the environmental integrity of the EU's climate strategy. Initially targeting six carbon-intensive sectors, the mechanism is expected to expand to all sectors currently covered by the ETS by 2030. In this paper, we refer to the initial stage as the *current CBAM*, and to the scenario where the CBAM is applied across all ETS sectors as the *full CBAM*. As a cross-border policy instrument, the CBAM effectively introduces a wedge between the cost of foreign producers and the price faced by importers, with potential implications for trade flows, input sourcing, and broader macroeconomic outcomes that remain uncertain and difficult to assess ex-ante.

In this paper, we propose a quantitative trade model to evaluate the effects of the CBAM on trade, emissions, and welfare. Our model is rich enough to account for the complexity of the world supply network and heterogeneity in the climate policy across countries. In particular, we incorporate input-output linkages at the country-sector level and endogenously determine national carbon prices[1], thereby capturing all types of instruments that put a price on emissions. We calibrate the model using publicly available data collected from standard sources. We find that the CBAM leads to a decrease in the share of carbon-intensive (dirty)

[1] We endogenize the emission prices in countries that have a functioning emission market.

imported intermediate inputs by 1.06% and an increase in non-carbon-intensive (clean) imported inputs and domestic inputs by 0.57% and 0.04%, respectively, suggesting the reallocation in intermediate input flows due to CBAM-induced trade barriers. The CBAM leads to a significant reduction in emissions embodied in direct imports by almost 4.80%. However, this number falls to 3% once we account for the emissions embodied in importers' supply chains, due to substitution towards non-targeted carbon-intensive inputs along the supply chains. Finally, we find a very small effect on the EU gross national expenditure (GNE), with the introduction of the CBAM leading to an increase of 0.006% in the EU GNE.

To evaluate the effects of the CBAM, we start by building a multi-country, multi-sector general equilibrium model with input-output linkages, building on Caliendo, Parro, and Tsyvinski (2022). In the model, a representative firm from each sector in each country produces output using labor and outputs produced by other sectors as inputs. The production technology exhibits constant returns to scale and, importantly, generates emissions as a by-product. Markets are perfectly competitive, and trade in intermediate inputs at the country-sector level shapes the structure of international supply chains. We model the CBAM as a price levied on the carbon content of selected carbon-intensive imported inputs. Importantly, this price is endogenously determined in the model: it is set to match the domestic price of the carbon content of the same sectoral goods, net of the foreign national environmental taxation. To our knowledge, we are the first to endogenize carbon prices and consequently the CBAM prices within a quantitative trade model.

Intuitively, the introduction of CBAM increases the price of carbon-intensive imports from countries with laxer regulations, prompting a reallocation of demand toward cleaner foreign producers and EU-ETS producers. This shift influences the demand for ETS allowances, thereby affecting their market price and, through the endogenous mechanism, the CBAM price itself. Thereby, in the model, we are capturing not only the direct effects of the policy but also its indirect feedback through emissions markets and allowance pricing.

We calibrate the model using publicly available and easily accessible data. In particular, we source data on bilateral trade flows, gross output, and value added from the OECD Inter-Country Input-Output tables, which collect data from 44 sectors across 32 countries, complemented by a residual Rest of the

World. We obtain tariffs from the World Trade Organization (WTO) Integrated Database and Consolidated Tariff Schedule. Finally, we obtain the emissions data from the OECD, complementing it with the data from the European Union Transaction Log (EUTL) database for some countries. In countries with an operational national carbon pricing scheme by 2024, we set the total supply of emissions to match the aggregate quantities we retrieve from the respective databases mentioned above. For countries without a pricing scheme in place, we impose an exogenous carbon price equal to the country-specific Effective Carbon Rate, sourced from the OECD, while the supply of emissions is determined endogenously.

We begin by examining how the CBAM affects international trade patterns, focusing on the following three outcomes: the average share of intermediate inputs the EU imports from abroad, the share of intermediate inputs EU sources domestically, and the size of EU sectors as measured by their average Domar weights in the world economy. Next, we turn to our core findings on the emissions embodied in EU imports and carbon leakage. We conclude by evaluating the impact of the CBAM on gross national expenditure in both the EU and its non-member countries. For each outcome, we compare the effects of the *current* and *full CBAM*, and distinguish between two scenarios: (i) a benchmark case in which the CBAM value adjusts with emission prices, referred to as the *endogenous* CBAM; and (ii) a case where the CBAM value is set according to the current mechanism but remains fixed, referred to as the *exogenous* CBAM.

We find that the current CBAM leads to roughly a 1.06% decline in the average share of imported carbon-intensive goods directly affected by the measure, encouraging a shift in demand towards cleaner alternatives. Accordingly, importers redirect demand toward non-carbon-intensive foreign input providers as well as domestic inputs. Domestic purchases of both clean and polluting goods grow by over 0.03%, reflecting partial substitution of foreign intermediate goods with locally produced alternatives. The size of dirty EU sectors (measured with Domar weight) decreases on average by 0.03% while the size of clean EU sectors increases by 0.11%. The former reduction is driven by an increase in the price of EU materials, thus, a higher marginal cost for EU producers. Notably, the model captures the general equilibrium impact of the CBAM beyond the sectors it directly regulates. The effects more than double under the full CBAM scenario.

Our key insights relate to the changes in emissions embodied in imports. The analysis distinguishes between direct emissions from imported goods and a broader measure that also includes indirect emissions along the importers' supply chains. We find that the current CBAM reduces European direct import-related emissions by 4.73% (8.84% under the full CBAM). When indirect imports are considered, the reduction in embodied emissions falls to 2.96% (5.19% under the full CBAM). The gap between the change in emissions embodied in direct and total – direct and indirect – imports reflects the broader substitution effects on the supply chain triggered by the policy. In the first instance, the CBAM directly reduces imports of carbon-intensive goods explicitly targeted by the adjustment mechanism. However, this decline induces substitution towards non-targeted inputs, whose relative price falls and whose demand correspondingly rises. As demand for these substitutes increases, so too does the demand for the inputs required to produce them – including carbon-intensive ones. This reallocation weakens the overall impact of the CBAM by increasing carbon emissions upstream. Although the latter is outside the scope of the present regulation, we argue that it is relevant to understand how to reach policy targets after capturing the full carbon footprints along global supply chains. On a higher level of aggregation, we find that the current CBAM should lead to a reduction of emissions leakage by 0.11%.

Interestingly, at the aggregate level, the current CBAM configuration increases real GNE by 0.006%, reaching 0.04% under the full CBAM scenario. The observed increase in EU welfare is primarily driven by terms-of-trade improvements resulting from a reallocation of demand that favors domestic production. These gains reflect higher export prices relative to imports, allowing the EU to obtain more imports per unit of exports and thus benefit from improved trade conditions. In contrast, extra-EU countries experience a minor decline in GNE, with reductions of 0.008% and 0.02% under the current and full CBAM scenarios respectively.

Intuitively, the effects of CBAM strongly depend on two factors: the emissions intensity of production technologies in source countries and the degree of the EU's integration into global supply chains. To explore these dimensions, we conduct two types of counterfactual exercises. First, to isolate the role of technology, we vary a measure of production cleanliness in source countries. Second, we vary the degree of the EU's integration into the global supply network. In both exercises, our primary outcome of interest is import-embodied emissions.

Our results show that cleaner global production technologies reduce the impact of CBAM in a more-than-proportional manner. In contrast, deeper supply chain integration weakens the policy's effectiveness by limiting the scope for substitution toward domestic inputs. Importantly, these two channels are interrelated: EU firms tend to source more heavily from countries that employ dirtier production technologies.

Related literature This paper bridges two different fields of literature: the literature on the trade effects of environmental policies, more specifically, the literature on carbon border adjustment, and the literature on production networks.

By extending the input-output model by Caliendo, Parro, and Tsyvinski (2022) to incorporate emissions in production, we contribute to the literature that studies the interactions between international trade, the environment, and environmental regulations through general equilibrium trade models (Duan et al. (2021), Larch and Wanner (2017), Larch and Wanner (2024), Korpar, Larch, and Stöllinger (2023), and Shi and Wang (2025)). Yet, differently from our framework, previous models do not fully map the global production networks, either because they assume that producers choose to buy inputs only from the lowest cost supplier – as in the workhorse model by Caliendo and Parro (2015) – or because they completely neglect the role of intermediate inputs in production.

There is a strand of the literature on carbon border adjustments largely relying on traditional Computable General Equilibrium (CGE) models (Böhringer et al., 2012; Ghosh et al., 2012; Böhringer et al., 2017; Mörsdorf, 2022; Bellora and Fontagné, 2023). Different from these papers, our quantitative trade model allows us to keep track of the economic mechanisms that generate the main results, avoiding the "black box" associated with CGEs.

The most related to our paper is the growing literature analyzing CBAM with structural trade models (Sogalla (2023), Campolmi et al. (2024), Flórez Mendoza, Reiter, and Stehrer (2024), Coster, Mejean, and Giovanni (2024), and Farrokhi and Lashkaripour (2025)). The papers closest to ours are: Flórez Mendoza, Reiter, and Stehrer (2024) and Coster, Mejean, and Giovanni (2024). Flórez Mendoza, Reiter, and Stehrer (2024) analyze the effect of the European CBAM on trade and emissions within a general equilibrium model. Their incorporation of country-sectoral production linkages *à la* Caliendo and Parro (2015) allows them to obtain disaggregated changes at the sectoral and country level. They find a negative, despite small, change in global emissions driven by the reallocation of production from carbon-intensive to less polluting countries. However, because their framework follows Caliendo and Parro (2015) in assuming that each sector imports a given input only from its lowest-cost supplier, it cuts many potential sourcing links and therefore restricts the extent of reallocation across alternative input sources. By contrast, by mapping the full global input-output network, we are able to quantify the propagation of CBAM through multiple direct and indirect channels. Our findings also complement those obtained by Coster, Mejean, and Giovanni (2024). They combine a structural trade model with product-level and balance sheet microdata, running quantitative simulations comparing carbon leakage and welfare effects of ETS-only versus ETS+CBAM scenarios. Their analysis focuses on French firms and captures firm-level sourcing decisions at both the intensive and extensive margin within a framework of monopolistic competition. They find that the CBAM reduces embedded emissions in French imports by inducing a reallocation of purchases toward cleaner inputs. By contrast, our model abstracts from firm heterogeneity and adopts a higher level of aggregation by focusing on sectors, rather than on firms. At the same time, we extend their analysis in several dimensions. First, we adopt a global country-sector perspective, which allows us to quantify the general equilibrium effects of CBAM across multiple sectors and countries. Second, we move beyond the Armington minimum-cost-supplier structure used in their framework and map the full international input-output network. This allows us to trace the propagation of the CBAM through the whole supply chain and to explicitly account for both direct and indirect (supply-chain-mediated) emissions by capturing the complete carbon footprint of global production. Finally, while all these papers treat the CBAM as an exogenous policy shock, we take into consideration its endogenous nature and its interaction with domestic climate policies by explicitly endogenizing both carbon prices and the CBAM prices.

Our work is also related to the literature on production networks (Baqaee and Farhi, 2020; Baqaee and Farhi, 2024; Carvalho et al., 2021). While our model is fairly standard and aligned with this literature, we are the first to examine the network effects of the carbon border adjustment policy.

Overall, we argue that our framework provides a comprehensive assessment of the economic and environmental implications of CBAM, contributing to a broader discussion on climate policy design in an interconnected global economy.

The remainder of the article is structured as follows. In Section 2 we provide more details about the CBAM. In Section 3, we introduce the theoretical framework, while Section 4 presents the results of the simulation of the policy. Finally, Section 6 concludes and offers some final thoughts on the future of CBAM.

2. INSTITUTIONAL SETTING

Global greenhouse gas (GHG) emissions have increased steadily since the beginning of the 21st century, despite international efforts to curb them (Dhakal et al., 2022). In response, the European Union has committed to reducing the net domestic greenhouse gas emissions by at least 55% by 2030 relative to 1990 levels, and achieving climate neutrality by 2050 (European Commission, 2021). Central to this strategy is the EU Emission Trading Scheme (ETS),[2], the first major carbon pricing market. The ETS is a cap-and-trade mechanism designed to reduce GHG emissions. It sets a limit (cap) on the total amount of emissions that can be produced by facilities covered under the system. To help achieve the EU's climate goals, this cap decreases annually, ensuring a gradual and consistent reduction in overall emissions. Within the emissions cap, allowances, measured in tons of CO_2 equivalent, are distributed through a combination of auctioning and free allocation. The system covers around 40% of European GHG emissions and, since its launch in 2005, it has helped drive down emissions from electricity, heat generation and industrial production by 47% (European Commission, 2024)[3].

One consequence of the ETS is that producers covered by the system may face a competitive disadvantage compared to similar producers in countries without a comparable carbon pricing scheme. This creates an incentive for EU firms to relocate carbon-intensive stages of production to countries with less stringent environmental regulations—a phenomenon commonly referred to as *carbon leakage*. As an illustration, Figure 1 shows the positive correlation between each non-ETS country's weighted average carbon intensity and their integration into the European supply network. We compute the weighted average carbon intensity by assigning to each sectoral pollution intensity a weight corresponding to the sector's share of total country's sales. Integration into the European supply

[2]The ETS is also in place in Norway, Liechtenstein, Northern Ireland, and Iceland
[3]See Appendix Figure A.3 for more details.

network corresponds, instead, to the share of both direct and indirect exports to the EU, relative to the country's total sales. The positive correlation underlines

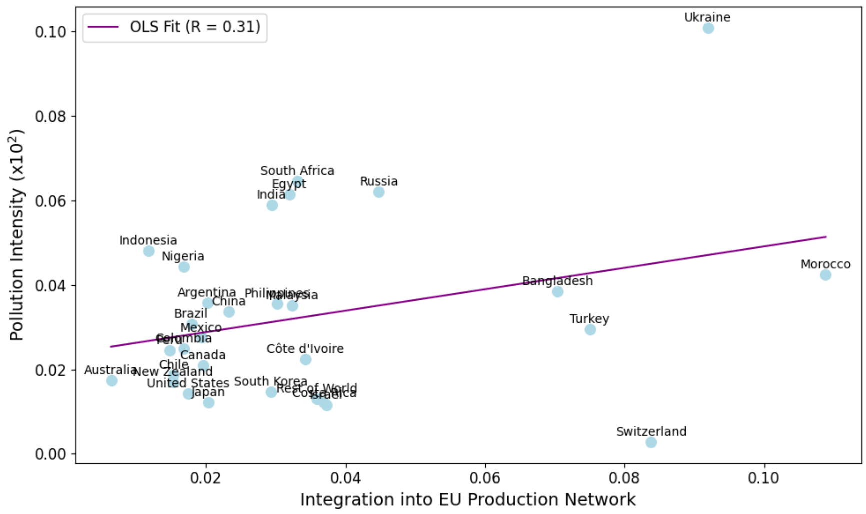


Figure 1: Carbon Intensity and Trade Integration into the EU supply network of non-ETS trading partners

an important feature of the EU's trade pattern: it is highly integrated with countries that tend to have emission-intensive production structures. This pattern creates a misalignment between EU's climate goals and the carbon content of its imports, undermining European's internal efforts by "offshoring" emissions through the purchase of carbon-intensive goods from foreign countries.

To address these concerns, in 2021, the European Commission proposed the introduction of the Carbon Border Adjustment Mechanism (CBAM), complementing it with the gradual phase-out of the free allowances. The CBAM is a policy tool designed to place a carbon price on the emissions embodied in imports of specific goods from non-EU countries, ensuring that importers face similar carbon costs as those borne by EU producers sourcing the same goods domestically. This aims to prevent carbon leakage and maintain the competitiveness of EU industries under the ETS. Under the CBAM, European importers are required to purchase and submit CBAM certificates corresponding to the embedded emissions in their imported goods. The price of these certificates is based on the weekly average closing price of EU ETS allowances on the auction platform. This mechanism ensures that EU producers continue to face carbon costs under the EU ETS, while foreign exporters of emissions-intensive goods are subject to a comparable carbon price, thereby leveling the playing field and reducing the risk of carbon leakage. By introducing a carbon price on the carbon content of imports, CBAM serves as a hybrid instrument of trade and climate policy, safeguarding the EU's climate targets from being undermined by emissions embodied in imports.

Since 2023, the CBAM has been in a transitional phase, requiring firms in selected sectors to report the embodied emissions of their imports without financial obligations. Starting in 2026, importers will be required to purchase CBAM certificates corresponding to the carbon content of covered goods (iron and steel, cement, aluminum, organic basic chemicals, hydrogen, fertilizers, and electricity). The mechanism is expected to expand to all imported goods corresponding to those falling under the ETS scheme by 2030.

In the following section, we develop a model to assess the impact of the CBAM on trade and emissions embodied in trade flows, and quantify its effectiveness as both a climate and competitiveness policy instrument.

3. THE MODEL

We develop a multi-country, multi-sector model with country-sectoral linkages and trade in intermediate goods, building on Caliendo, Parro, and Tsyvinski (2022). There is a set $\mathcal{N} = \{1, ..., N\}$ of countries, indexed by i and n, and a set $\mathcal{J} = \{1, ..., J\}$ of sectors for each country, indexed by j and k. We use subscripts to denote countries, and superscripts to denote sectors.

Intermediate and final goods production.

Each sector j in country i is represented by a competitive producer that produces a single good using labor l_i^j and materials M_i^j as inputs. Each sectoral good can be either consumed as a final good by the household or used as an intermediate input in the production of other goods. Since each sector produces one good, we will use terms *good/input* and *sector* interchangeably when there is no fear of ambiguity. Following Copeland and Taylor (2003), we assume that a fraction $a_i^j \in (0, 1)$ of input mix is used to abate pollution. We use q_i^j to denote the output of sector j in country i, and assume that producers combine inputs in a Cobb-Douglas fashion. The production function exhibits constant returns to scale and has the following form:

$$q_i^j = \Upsilon_i^j A_i^j (1 - a_i^j)(l_i^j)^{\beta_i^j} (M_i^j)^{1-\beta_i^j}, \tag{1}$$

where A_i^j is a Hicks-neutral parameter, l_i^j denotes the labor input, and $\beta_i^j > 0$ is its share in production. Υ_i^j is a normalizing constant, that we specify later. Moreover, we define materials M_i^j as a CES aggregate of intermediate goods used in the production, namely:

$$M_i^j = \left(\sum_{n \in \mathcal{N}} \sum_{k \in \mathcal{J}} (\iota_{ni}^{kj})^{\frac{1}{\theta}} (z_{ni}^{kj})^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}}, \tag{2}$$

where z_{ni}^{kj} is the amount of intermediate good produced by sector k located in country n used in the production of good j in country i. Parameter θ governs the substitutability between intermediate inputs. The coefficient $\iota_{ni}^{kj} \geq 0$ measures the relevance that good of sector k produced in country n has in the production of good of sector j in country i, with $\sum_{n \in \mathcal{N}} \sum_{k \in \mathcal{J}} \iota_{ni}^{kj} = 1$. In particular, if $\iota_{ni}^{kj} = 0$, the specific good produced by sector k in country n is not used in the production of good j in country i.

We assume that each sector generates emissions e_i^j as a by-product. The amount of emissions negatively depends on the abatement, with ρ_i^j being the emissions elasticity:

$$e_i^j = (1 - a_i^j)^{\frac{1}{\rho_i^j}} \left[A_i^j (l_i^j)^{\beta_i^j} (M_i^j)^{1-\beta_i^j} \right]. \tag{3}$$

Expressing $(1 - a_i^j)$ from (3) and plugging it into the production function (1), total output q_i^j can be rewritten as a function of both polluting emissions and inputs:

$$q_i^j = \Upsilon_i^j \left[A_i^j (l_i^j)^{\beta_i^j} (M_i^j)^{1-\beta_i^j} \right]^{1-\rho_i^j} [e_i^j]^{\rho_i^j}, \tag{4}$$

where, for convenience, we use the following normalization:

$$\Upsilon_i^j = \left[(\beta_i^j)^{-\beta_i^j} (1 - \beta_i^j)^{-(1-\beta_i^j)} \right]^{1-\rho_i^j} (1 - \rho_i^j)^{-(1-\rho_i^j)} (\rho_i^j)^{-\rho_i^j}. \tag{5}$$

Given the functional form of the emissions' function, under the assumption that $a_i^j \in (0, 1)$, there is a one-to-one mapping between the emissions e_i^j and the abatement a_i^j. In the following, we treat e_i^j as the producers' choice variable and use equation (4) as our production function. The same approach is taken, for instance, in Shapiro and Walker (2018).

Emissions.

Following Bellora and Fontagné (2023), we distinguish between countries that have a national carbon market (belonging to the set $\mathcal{N}_c$) and countries that have not adopted any pricing mechanism on emissions ($\mathcal{N}_{nc}$). For the first group, we consider a national inelastic supply of emissions, and the unit price of emissions t_i is determined endogenously to equate the aggregate demand for emissions with the available supply. This price can be interpreted as the shadow price of all regulations applying a price on emissions. Specifically, in cap-and-trade systems, total national emissions are limited by the total number of allowances, each of which permits the emission of one unit e_i^j of polluting emissions. Accordingly, t_i represents the market price of these emission permits, which may either be purchased or allocated for free. We let $\epsilon_i^j \in (0, 1)$ denote the share of emission permits that are freely distributed to a sector j in country i, relative to the total number of permits, and adjust national supply by discounting for the free allowances. In contrast, for countries in $\mathcal{N}_{nc}$, we impose an exogenous carbon price. In this case, the supply of emissions permits is endogenously determined to match the demand at the given price.

International trade and CBAM.

We assume that trade across countries and sectors is costly and subject to frictions modeled as a combination of iceberg trade costs $d_{ni}^{kj} \geq 1$, with $d_{ii}^{kj} = 1\ \forall i, n, k, j$, and ad-valorem tariffs κ_{ni}^{kj}[4]. Importantly, we directly incorporate the Carbon Border Adjustment Mechanism (CBAM) that targets the emissions embodied in trade, as an additional trade friction. Recall that the CBAM aims to ensure that imported goods face a comparable carbon cost to domestically produced goods, to mitigate carbon leakage and level the playing field.

We model CBAM as a price wedge that equalizes the carbon cost of imported goods with the domestic carbon price, net of any carbon price already paid in the exporting country. When the exporting country imposes a higher, or equal, carbon price ($t_n \geq t_i$), we assume that no CBAM adjustment is applied. The total price wedge for good k originating in country n, when imported by sector

[4] We retain the destination sector index j to capture potential heterogeneity in tariffs across importing sectors and to maintain flexibility for more realistic modeling.

j in country i is therefore given by:

$$\tau_{ni}^{kj} = d_{ni}^{kj} \overbrace{(1 + \kappa_{ni}^{kj} + CBAM_{ni}^{kj})}^{\equiv \tilde{\tau}_{ni}^{kj}}, \tag{6}$$

where:

$$CBAM_{ni}^{kj} = \begin{cases} \rho_n^k t_i \text{ if } t_n = 0 \\ \rho_n^k \frac{t_i}{t_n} \text{ if } t_i > t_n > 0, i \in \tilde{\mathcal{N}} \subseteq \mathcal{N}, n \notin \tilde{\mathcal{N}} \subseteq \mathcal{N}, k \in \tilde{\mathcal{J}} \subseteq \mathcal{J}. \\ 0 \text{ otherwise} \end{cases} \tag{7}$$

To simplify notation, we define $\tilde{\tau}_{ni}^{kj} \equiv 1 + \kappa_{ni}^{kj} + CBAM_{ni}^{kj}$. Our modeling approach is coherent with the predominant approach in literature that models carbon border adjustments as an additional tariff[5].

We examine two distinct approaches to determining the value of CBAM, which we label *exogenous* and *endogenous* CBAM. When the value of CBAM is set based on the prevailing vector of emission prices $\mathbf{t}$, we refer to this as the exogenous case. However, because the introduction of CBAM generally alters the relative carbon prices across countries, we define the endogenous CBAM as the value that emerges when emission prices $\mathbf{t}$ adjust in response to the implementation of CBAM. This is a distinguishing feature of our approach and is not incorporated in related work.

Therefore, under perfect competition, the price of one unit of good k shipped from country n to sector j in country i is given by:

$$p_{ni}^{kj} = mc_n^k \tau_{ni}^{kj} = \frac{1}{(A_n^k)^{1-\rho_n^k}} \left[w_n^{\beta_n^k} (P_n^k)^{1-\beta_n^k} \right]^{1-\rho_n^k} \left[t_n (1 - \epsilon_n^k) \right]^{\rho_n^k} \tau_{ni}^{kj}$$

where w_n is the wage in country n, t_n is the price of carbon emissions, ϵ_n^k is the share of free allowances and $P_n^k = \left(\sum_{i \in \mathcal{N}} \sum_{j \in \mathcal{J}} \iota_{ni}^{kj} (p_{ni}^{kj})^{1-\theta} \right)^{\frac{1}{1-\theta}}$ is the price index.

[5] Recent examples modeling the European CBAM as an additional tariff include Bellora and Fontagné (2023), Campolmi et al. (2024), Larch and Wanner (2024), Flórez Mendoza, Reiter, and Stehrer (2024), and Coster, Mejean, and Giovanni (2024).

Households.

In each country i, there is a representative household supplying $\bar{L}_i$ units of labor inelastically. Moreover, in the subset of countries $\mathcal{N}_c \subseteq \mathcal{N}$ having a national carbon market, they also provide emissions permits, where E_i denotes the total supply of emissions in country i. Preferences over sectoral final goods included in the bundle $\mathbf{c}_i = (c_i^1, ..., c_i^J)$ in each country $i \in \mathcal{N}$ are represented by the following CES utility function:

$$u(\mathbf{c}_i) = \left(\sum_{j \in \mathcal{J}} (\chi_i^j)^{\frac{1}{\sigma}} (c_i^j)^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}} \tag{8}$$

where $\chi_i^j \geq 0$ denotes the weight that the consumption of good j has in total consumption, with $\sum_{j \in \mathcal{J}} \chi_i^j = 1$ and σ is the elasticity of substitution between final goods.

Households receive lump-sum transfers, derived from the collection of tariffs and CBAM, and transfers from the rest of the world in the form of exogenous trade deficits $\overline{D_i}$. The budget constraint is therefore given by:

$$\sum_{j \in \mathcal{J}} p_i^j c_i^j \leq I_i = w_i \overline{L}_i + t_i E_i + \sum_{j \in \mathcal{J}} \sum_{n \in \mathcal{N}} \sum_{k \in \mathcal{J}} (\kappa_{ni}^{kj} + CBAM_{ni}^{kj}) p_{ni}^{kj} z_{ni}^{kj} + \overline{D_i}$$

where $\sum_{j \in \mathcal{J}} p_i^j c_i^j$ is country i's Gross National Expenditure (GNE). Given locally non-satiated preferences, the constraint is satisfied with equality, and the solution to the consumer's problem yields the following optimal consumption of final good c_i^j:

$$c_i^j = \frac{I_i}{\sum_{k \in \mathcal{J}} (\chi_i^k / \chi_i^j)(p_i^k)^{1-\sigma} (p_i^j)^{\sigma}} \quad \forall i \in \mathcal{N}, j \in \mathcal{J}$$

Equilibrium.

We begin by defining the equilibrium in the case where the CBAM value is fixed based on the initial vector of emission prices $\mathbf{t}$ and does not respond to subsequent price changes triggered by the introduction of CBAM, as discussed earlier in this Section. We then extend this definition to allow the CBAM value to adjust endogenously in response to the price shifts induced by the trade barrier it introduces.

Definition 3.1 (Equilibrium). — *Given productivities* A_i^j, *wedges* $d_{ni}^{kj}, \kappa_{ni}^{kj}$, *the fixed values of* $CBAM_{ni}^{kj}$ *and a vector of trade deficits* $\overline{D_i}$ *such that* $\sum_{i \in \mathcal{N}} \overline{D_i} = 0$, *the equilibrium is the set of wages* w_i^*, *carbon prices* t_i^* *and prices of goods* p_i^{j*}, *intermediate inputs choices* z_{ni}^{kj*}, *factor input choices* l_i^{j*}, e_i^{j*}, *outputs* q_i^{j*} *and final demands* c_i^{j*} *such that:*

- *in each country, final demand maximizes the consumer's utility subject to the budget constraint;*
- *in each sector and country, producers maximize their profits, taking prices as given;*
- *markets for produced goods, labor, and emissions clear.*

In definition 3.1, the CBAM is determined according to equation (7) with prices $\mathbf{t}$ equal to the equilibrium prices in the absence of CBAM — that is, the equilibrium prices prior to the introduction of the CBAM. We refer to the resulting outcome as the equilibrium with *exogenous* CBAM. The equilibrium will be said to be the equilibrium with *endogenous* CBAM when the prices $\mathbf{t}$ in (7) are equal to the equilibrium prices for that level of CBAM. In the next section, we discuss how we solve for both types of equilibria.

Input-Output Definitions.

Our model conceptualizes the world economy as a network, where each node represents a sector in a country, and the links denote the flows of intermediate inputs between these sector-country pairs. One of the goals of our analysis is to evaluate the role of the structure of this network in mediating the effects of the CBAM. To ease the analysis of the model, we introduce additional notation.

To facilitate calibration, we define the steady state of the economy as the situation in which wedges d_{ni}^{kj} and κ_{ni}^{kj} are equal to zero for all combinations of i, n, k, j. Furthermore, we normalize the hicks productivity parameter A_i^j such that $(1-\epsilon_i^j)^{\rho_i^j} A_i^{j-(1-\rho_i^j)} = 1$.[6]

[6]Note that this is equivalent to appropriately rewriting the normalization constant Υ_i^j in (5).

- The *cost share* of intermediate input k produced in country n in the total intermediate inputs used in sector j in country i is denoted by $\tilde{\omega}_{ni}^{kj}$ and, in equilibrium, it corresponds to:

$$\tilde{\omega}_{ni}^{kj} \equiv \frac{p_{ni}^{kj} z_{ni}^{kj}}{P_i^j M_i^j} = \iota_{ni}^{kj} \left(\frac{p_{ni}^{kj}}{P_i^j} \right)^{1-\theta} = \frac{\iota_{ni}^{kj} (p_{ni}^{kj})^{1-\theta}}{\sum_{n \in \mathcal{N}} \sum_{k \in \mathcal{J}} \iota_{ni}^{kj} (p_{ni}^{kj})^{1-\theta}}$$

  We denote the set of $N \times M$ real matrices by $\mathcal{M}(N \times M)$ and let $\tilde{\mathbf{\Omega}} \in \mathcal{M}(NJ \times NJ)$ be the matrix with elements $\tilde{\omega}_{ni}^{kj}$, which records the direct inter-country and inter-sector flows of intermediate goods. In the steady state this matrix coincides with $\mathbf{\Pi} \in \mathcal{M}(NJ \times NJ)$, with entries ι_{ni}^{kj}.

- The expenditure share of intermediate input k produced in country n in the total sales of sector j in country i, is denoted by ω_{ni}^{kj} and, in equilibrium, it corresponds to the following *revenue share*:

$$\omega_{ni}^{kj} \equiv \frac{1}{\tilde{\tau}_{ni}^{kj}} \frac{p_{ni}^{kj} z_{ni}^{kj}}{p_i^j q_i^j} = (1 - \beta_i^j)(1 - \rho_i^j) \frac{\tilde{\omega}_{ni}^{kj}}{\tilde{\tau}_{ni}^{kj}}$$

  Similarly, let $\mathbf{\Omega} \in \mathcal{M}(NJ \times NJ)$ be the matrix with entries ω_{ni}^{kj} and define the Leontief inverse $\mathbf{\Psi} \in \mathcal{M}(NJ \times NJ)$ with entries ψ_{ni}^{kj} as:

$$\mathbf{\Psi} \equiv [\mathbf{I} - \mathbf{\Omega}]^{-1} = \mathbf{I} + \mathbf{\Omega} + \mathbf{\Omega}^2 + ...$$

  The matrix $\mathbf{\Psi}$ accounts for all direct and indirect linkages of the production network and, in the steady state, it corresponds to $\mathbf{\Psi} = (\mathbf{I} - \boldsymbol{\gamma}\mathbf{\Pi}')^{-1}$, where $\boldsymbol{\gamma} = diag(\gamma_1^1, ..., \gamma_N^J) \in \mathcal{M}(NJ \times NJ)$ and $\gamma_i^j = (1 - \beta_i^j)(1 - \rho_i^j)$.

- The share of good j purchased by the representative household in country i is denoted by α_i^j and, in equilibrium, it corresponds to the following *consumption share*:

$$\alpha_i^j \equiv \frac{p_i^j c_i^j}{\sum_{j \in \mathcal{J}} p_i^j c_i^j} = \frac{p_i^j c_i^j}{I_i} = \chi_i^j \frac{(p_i^j)^{1-\sigma}}{\sum_{j \in \mathcal{J}} \chi_i^j (p_i^j)^{1-\sigma}}$$

  In the steady state, it coincides with χ_i^j.

- Total sales as a share of nominal world GNE are equal to the *Domar weights* (in the world economy) and they are defined as:

$$\lambda_i^j \equiv \frac{p_i^j q_i^j}{GNE} = \frac{p_i^j q_i^j}{\sum_{i \in \mathcal{N}} \sum_{j \in \mathcal{J}} p_i^j c_i^j}$$

4. QUANTIFYING THE EFFECT OF THE CBAM

In this section, we apply the model from the previous section to evaluate the effects of the introduction of the CBAM on trade across sectors and countries, emissions embodied in imports, carbon leakage, gross national expenditure, and real wages.

We solve the model in changes using hat algebra approach (Dekle, Eaton, and Kortum, 2008), enabling us to evaluate different counterfactual scenarios. A desirable feature of this approach is that it captures the full non-linear adjustments to a finite – though not necessarily marginal – policy shock, while keeping computational efficiency. To complement this analysis and to illustrate the mechanisms at play, we provide comparative statics analysis of the effects of a marginal adjustment in CBAM in the Appendix A.2.

In our analysis, we consider both the adjustment to the equilibrium with exogenous CBAM and endogenous CBAM, as explained in the previous section. Unlike standard trade tariffs, which are fixed, the CBAM adjusts in response to domestic and foreign carbon prices – both of which may be influenced by the implementation of CBAM itself. By considering both cases, we can assess the significance of this additional adjustment mechanism. Furthermore, we distinguish between the current CBAM and a full CBAM. As noted in the introduction, the current CBAM applies only to a subset of goods, which in our analysis correspond to six sectors: Mining and Quarrying; Chemicals and Chemical Products; Non-Metallic Mineral Products; Basic Metals; Fabricated Metal Products; and Electricity, Gas, Steam, and Air Conditioning Supply. In contrast, the full CBAM extends coverage to all sectors of the EU economy currently covered by the ETS.

Solving the model in changes.

We use exact hat-algebra as developed by Dekle, Eaton, and Kortum (2008) to characterize a counterfactual equilibrium in terms of proportional changes relative to the steady state. Specifically, the equilibrium in relative changes is computed by solving the following system of non-linear equations that jointly determine changes in wages, intermediate input prices, carbon prices and emissions, cost and consumption shares, expenditures, and accounts for the endogenous nature of the CBAM.

DEFINITION 4.1. — *For any variable, let x denote the value before the introduction of the CBAM and x' denote the counterfactual value. Define $\hat{x} \equiv \frac{x'}{x}$ as the relative change of the variable. The equilibrium conditions in relative changes satisfy:*

- *Cost of the input bundle:*

$$\hat{mc}_i^j = \left(\hat{w}_i^{\beta_i^j} (\hat{P}_i^j)^{1-\beta_i^j}\right)^{1-\rho_i^j} \left(\hat{t}_i(1-\hat{\epsilon}_i^j)\right)^{\rho_i^j} \tag{9}$$

- *Tariffs:*

$$\hat{\tau}_{ni}^{kj'} = \frac{1+\kappa_{ni}^{kj} + \rho_n^k \frac{t_i'}{t_n'} \nu_{i,n}}{1+\kappa_{ni}^{kj}} \tag{10}$$

  where $\nu_{i,n}$ is the ratio between the observed carbon prices of country i and n[7]*.*

- *Price index:*

$$\hat{P}_i^j = \left(\sum_{n\in\mathcal{N}} \sum_{k\in\mathcal{J}} \iota_{ni}^{kj} (\hat{mc}_n^k \hat{\tau}_{ni}^{kj})^{1-\theta}\right)^{\frac{1}{1-\theta}} \tag{11}$$

- *Cost shares:*

$$\hat{\omega}_{ni}^{kj} = \left(\frac{\hat{mc}_n^k \hat{\tau}_{ni}^{kj}}{\hat{P}_i^j}\right)^{1-\theta} \tag{12}$$

- *Consumption shares:*

[7] In our model, quantities are normalized using specific country-sector parameters. This implies that the equilibrium carbon prices may correspond to different physical amounts of emissions. In order to compare them in a meaningful way, we need to map the equilibrium carbon prices back to the observed carbon prices, which we do through the constant $\nu_{i,n}$.

$$\hat{\alpha}_i^j = \left(\frac{\hat{p}_i^j}{\left(\sum_{j \in \mathcal{J}} \chi_i^j (\hat{p}_i^j)^{1-\sigma}\right)^{\frac{1}{1-\sigma}}} \right)^{1-\sigma} \tag{13}$$

where $\hat{p}_i^j = \hat{mc}_i^j$.

- *Total sales of in each country i and sector j:*

$$p_i^{j'} q_i^{j'} = \alpha_i^{j'} I_i' + \sum_{n \in \mathcal{N}} \sum_{k \in \mathcal{J}} \omega_{in}^{jk'} p_n^{k'} q_n^{k'} \tag{14}$$

where $I_i' = w_i' \overline{L_i} + t_i' E_i' + \sum_{j \in \mathcal{J}} p_i^{j'} q_i^{j'} \sum_{n \in \mathcal{N}} \sum_{k \in \mathcal{J}} (\tilde{\tau}_{ni}^{kj'} - 1) \omega_{ni}^{kj} + \overline{D_i}$

- *labor market clearing:*

$$\hat{w}_i = \frac{1}{w_i \overline{L_i}} \sum_{j \in \mathcal{J}} \beta_i^j (1 - \rho_i^j) p_i^{j'} q_i^{j'} \tag{15}$$

- *Emission market clearing:*

$$\begin{cases} \hat{t}_i = \frac{1}{t_i \overline{E_i}} \sum_{j \in \mathcal{J}} \rho_i^j p_i^{j'} q_i^{j'} & \forall i \in \mathcal{N}_c \\ \hat{E}_i = \frac{1}{t_i E_i} \sum_{j \in \mathcal{J}} \rho_i^j p_i^{j'} q_i^{j'} & \forall i \in \mathcal{N}_{nc} \end{cases} \tag{16}$$

The endogenous nature of CBAM is visible from equation (10), where the part of the total tariffs which is due to CBAM ($\rho_n^k \frac{t_i'}{t_n'}$) depends on the counterfactual values of prices. In the case of exogenous CBAM, this term changes to ($\rho_n^k \frac{t_i}{t_n}$), where t_i and t_n are the price levels in the equilibrium prior to the introduction of CBAM.

We solve the system using a fixed point iteration algorithm, similar to the one used in Caliendo and Parro (2015) and Mayer, Vicard, and Zignago (2019), following the steps below:

1. Guess the initial vectors of changes for **w** and **t**;
2. Use equation (10) to derive the change in tariffs, after the introduction of the CBAM in the counterfactual scenario;
3. Use Equations (11)-(13) to solve for the change in prices, cost shares and consumption shares;

4. Given the change in trade shares and income, retrieve the counterfactual level of expenditure for each country-sector pair through equation (14) ;

5. Aggregating over sectors, labor market clearing in (15) and market clearing for emissions in (16) imply an update of the initial conditions, dampened by a factor of 0.1.

6. Iterate until convergence, i.e., until the norm of the difference between successive iterations falls below a given threshold.

Calibration and the baseline.

Solving the model in relative changes has the advantage of reducing the data needed for the calibration. We rely on a minimal yet sufficient set of macroeconomic and environmental data, which enhances the transparency, tractability, and ease of replication of our exercise. Specifically, we calibrate the model on data for the last available year 2018[8]. In particular, we work on bilateral trade flows in intermediate inputs and final goods, gross output and value added sourced from the OECD Inter-Country Input-Output tables (Cimper, Zürcher, and Han, 2021), which collects data from 44 sectors across 32 countries, complemented by a residual Rest of the World. With these data, we can retrieve the empirical counterparts for the steady state values of the cost shares ι_{ni}^{kj}, the labor input shares β_i^j, the consumption shares χ_i^j and the exogenous deficits $\bar{D}_i$. Then, we source tariffs from the WTO Integrated Database and Consolidated Tariff Schedule[9], while we retrieve Scope 1 emissions from production from the OECD Environmental Statistics database. In order to build the emissions elasticity ρ_i^j, emissions quantities are multiplied by the corresponding country's Effective Carbon Rate (OECD, 2023), converted into USD using the OECD exchange rate. For the European Union, Iceland and Norway, we employ a different approach. We collect emissions data from the European Union Transaction Log (EUTL) database. We aggregate these data at the selected sectoral level and adjust the

[8]See A.1 for a detailed exposition of the mapping of the model to the data. Following Bellora and Fontagné (2023), we construct the baseline year (2024) by incorporating environmental policies implemented between 2018 and 2024. The effects of the CBAM are then assessed relative to this baseline. Further details are provided later in this section.

[9]We follow Baqaee and Farhi (2024), and calibrate the model using observed trade value data that we adjust for existing tariffs. This practically means that in our quantitative exercise, we set $\kappa_{ni}^{kj} = 0$ at the baseline.

reported emissions by deducting those covered by free allowances granted to the installations operating in Energy Intensive Trade Exposed (EITE) industries. Note that this choice implies that we will evaluate lower bounds for both the level and the variation of emissions in these countries, as the data source excludes emissions from entities not covered by the ETS. For this reason, we refer to *EU emissions* and *ETS emissions* interchangeably, unless the distinction is necessary to avoid ambiguity.

In countries with an operational national carbon pricing scheme by 2024, we set the total supply of emissions to match the aggregate quantities we retrieve from the respective databases, described above. For countries without a pricing scheme in place by 2024[10], we impose an exogenous carbon price equal to the country-specific Effective Carbon Rate, while the supply of emissions is determined endogenously. Finally, consistent with Caliendo, Parro, and Tsyvinski (2022), we assume an elasticity of substitution between intermediate goods and final consumption goods equal to 4, constant across countries and sectors.

The construction of the baseline. Before introducing the CBAM, we run a simulation in which, following Bellora and Fontagné (2023), selected countries implement their emissions reduction pledges under the Paris Agreement. Then we use the resulting equilibrium as our baseline. Rather than comparing the scenario where the CBAM is introduced with the original 2018 steady state, we adopt this policy-adjusted baseline for two main reasons. First, the implementation of the Paris Agreement commitments is binding for many countries, making it more representative of the environment where the CBAM operates. Second, it allows us to isolate the specific contribution of the CBAM, net of the ongoing climate policy changes.

We build the policy-adjusted baseline in the following way. We select the countries with a carbon pricing scheme and consider the unconditional targets declared in their 2020 Nationally Determined Contributions (NDCs) under the

[10]We collect details about direct carbon pricing initiatives around the world on the *World Bank Carbon Pricing Dashboard* (`https://carbonpricingdashboard.worldbank.org/`). The full list includes: Bangladesh, Brazil, Côte d'Ivoire, Costa Rica, Egypt, India, Israel, Morocco, Malaysia, Nigeria, Peru, Philippines, Russia, Turkey, and the United States. Moreover, we include China in this list, since we believe its current environmental regulation is not stringent enough to incentivize decarbonisation efforts.

Paris Agreement[11]. We convert all the considered commitments into a fixed target level for the year 2030 and derive a yearly percentage reduction rate from the declared base year, consistent with each country's target. We then apply an exponential decay from 2018 to 2024, in order to model emission trajectories. Two notable exceptions apply. First, as for ETS countries, we also consider a 40% reduction in the freely allocated allowances relative to 2018 levels, as supported by empirical data (see Figure A1). Second, as for China, we follow Bellora and Fontagné (2023) in assuming the absence of a fully operational carbon market. We believe that its current carbon price is too low to reach the targets declared in the country's NDC[12] and, accordingly, we treat China's carbon price as exogenous.

We impute the computed change in emissions between 2018 and 2024 and simulate the counterfactual equilibrium. The resulting cost-shares and consumption shares, together with the new pollution intensity parameters, are then used to recalibrate the model and build our new baseline.

Policy scenarios. We assume that standard trade tariffs remain constant and introduce the CBAM as a price wedge applied to the embodied emissions in imports of targeted goods entering the EU, as defined in equation (6). Given the gradual phase-in of the policy specified in Regulation (EU) 2023/956, we consider two counterfactual scenarios:

- *Current CBAM*: under the Regulation, the border adjustment initially applies only to specific goods – iron and steel, cement, aluminum, organic basic chemicals, hydrogen, fertilizers, and electricity. In our exercise, they correspond to six broader sectors: Mining and Quarrying, Chemicals and Chemical Products, Non-Metallic Mineral Products, Basic Metals, Fabricated Metal Products, and Electricity, Gas, Steam, and Air Conditioning Supply;

- *Full CBAM*: in this scenario, the adjustment is extended to all imported goods corresponding to the categories falling under the EU-ETS coverage.

[11] We consider the most recent unconditional pledges submitted to the NDCs Registry as of 2024. Conditional targets are excluded from this exercise.

[12] According to the OECD (2023), in the last year recorded, coinciding with 2023, the Effective Carbon Rate was EUR 7.27 per tonne of CO_2e.

5. RESULTS

In this section, we present our main findings. We begin by analyzing how the CBAM affects international trade patterns, focusing on the following three outcomes: the average share of intermediate inputs the EU imports from abroad, the share of intermediate inputs EU sources domestically, and the size of EU sectors as measured by their average Domar weight in the world economy. We report these results in Table 1. Next, we turn to our core findings on carbon leakage and emissions embodied in EU imports, summarized in Table 2. We conclude by evaluating the impact of the CBAM on gross national expenditure in both the EU and non-EU countries, and report the results in Table 3. For each outcome, we compare the implications of the current versus full CBAM and distinguish between scenarios in which the value of the CBAM is set endogenously and exogenously, as discussed in Section 3. Our preferred specification is the one with current and endogenous CBAM, reported in the first column of Tables 1–3.

When discussing our results in the following paragraphs, we will use the terms *dirty/carbon-intensive* goods to refer to the sectoral goods falling under the ETS scheme[13], while classifying the residual sectoral goods as *clean/non-carbon-intensive*.

We start by examining how the patterns of international trade are affected by the CBAM. By design, the CBAM increases the price of imported carbon-intensive goods at the EU border, creating a price wedge that alters the relative competitiveness of domestic and foreign producers. Therefore, we first ask a question about whether and to what extent the introduction of the CBAM causes the European firms to substitute away from dirty imported inputs.

As reported in Panel (a) in Table 1, this mechanism leads, under the current CBAM, to a decline in the average share of foreign purchases – corresponding to the average share of European imports from all other countries in total intermediate input purchases – of 0.60%. This number more than doubles in the full CBAM scenario. The reported effects are similar across endogenous and exogenous CBAM scenarios. The additional adjustment of the value of CBAM in the endogenous scenario leads to an increase of the effect by 5% (from 0.57% to 0.60%) under the current CBAM, and 3% under full CBAM. At a more granular

[13]See Table A1 for the classification of sectors falling under the ETS.

level, while the CBAM leads to a contraction in the shares of foreign purchases of carbon-intensive sectoral goods directly targeted by the policy (with a 1.06% decrease under the current CBAM, reaching 2.14% under the full CBAM), there is a reallocation of the input demand towards cleaner alternatives driven by substitution effects, with an increase in the average share of foreign purchases of non-carbon-intensive goods of 0.57% under the current CBAM scenario, expanding to 1.91% under the full CBAM.[14]

Panel (b) offers a complementary perspective to Panel (a) and presents the effect on the share of intermediate inputs sourced within the EU. The additional cost introduced by the CBAM leads to a partial substitution away from more expensive foreign intermediate inputs in favour of domestically produced goods, inducing a reallocation of purchases of intermediate goods towards the EU, more so for clean than for dirty inputs. Under the current CBAM, domestic purchases of clean goods rise by 0.08%, while those of polluting goods increase by 0.03%. These effects are widened under the full CBAM, with domestic purchases of clean goods rising to 0.10% and those of polluting goods to 0.07%.

Finally, Panel (c) in Table 1 shows the average change in Domar weights (defined in Section 3). Despite the small albeit positive overall change, disaggregated results reveal a difference between clean and dirty goods. The clean sectors become bigger, since other sectors substitute dirty foreign inputs with domestic clean inputs. The average Domar weight of clean sectors exhibits an increase of 0.11% under the current CBAM (0.29% under the full CBAM), whereas the corresponding share of dirty goods declines marginally in both scenarios. This asymmetric effect stems from the different reliance of clean and dirty producers on carbon-intensive inputs: while the CBAM raises unit production costs for all producers by increasing the price index, clean producers are less exposed to this shock due to their lower input carbon intensity. As a result, their relative competitiveness increases, while European carbon-intensive sectors suffer a loss of sales shares due to a shift in the geographical sourcing of such goods. In fact, importers in other countries are more likely to reallocate their demand away from the European Union and towards third-country producers.

The comparison of the cases with endogenous vs. exogenous CBAM shows

[14]The magnitude of these substitution effects clearly depends on the elasticity of substitution across intermediate inputs, captured with θ. As shown in Table A3, a higher elasticity amplifies the reallocation from dirty to cleaner inputs, magnifying the effects of the policy.

that the substitution effects in intermediate inputs are magnified by the endogenous adjustment, as a result of the feedback loop between the CBAM and the equilibrium carbon prices. As the CBAM increases the relative price of foreign carbon-intensive goods, demand shifts towards cleaner and domestic substitutes. This reallocation reduces production abroad and raises it at home, leading to a decrease in foreign carbon prices – due to lower carbon input demand – and an increase in the domestic carbon prices. Since the CBAM responds negatively to foreign carbon prices and positively to domestic ones, the differential widens, increasing the value of the CBAM. These general equilibrium feedbacks magnify the substitution away from foreign inputs. Hence, the magnification in Panel (a) when moving from exogenous towards endogenous CBAM.

The effect of CBAM is heterogeneous across trade partners. The magnitude of the border adjustment varies across countries and sectors due to three key factors: (i) the pollution intensity of the production process; (ii) the relative stringency of carbon pricing; (iii) the sectoral composition of exports to the EU. These heterogeneous effects are illustrated by Figure 2, which depicts the change in the share of carbon-intensive foreign purchases for the ten largest exporting countries of polluting inputs to the EU (Panel 2a). Interestingly, the introduction of the CBAM leads to an increase in shares of purchases from some of these countries. The increase in the share from Switzerland and Norway is straightforward to interpret: since the CBAM does not apply to imports from countries that are either part of the EU-ETS or have a domestic ETS fully linked with it (as in the case of Switzerland), their exports are not subject to the additional carbon price wedge. As a result, these countries gain a relative cost advantage compared to exporters from countries whose goods are targeted by the CBAM, which translates into increased export shares to the EU. The cases of Japan and South Korea are different. Both countries are major exporters of carbon-intensive goods to the EU, yet they display distinctive patterns in response to the CBAM with respect to the other trading partners. This is because Japan has relatively low carbon intensity in the production of carbon-intensive goods (see Table A2), while South Korea has a relatively high carbon price (see Figure A4). Both factors lead to low CBAM relative to these countries. When we consider the reduction in the shares of foreign purchases from the top 10 most affected countries (Panel 2b) our results are aligned with the Relative CBAM

Variable	Current CBAM		Full CBAM	
	Endog.	*Exog.*	***Endog.***	*Exog.*
Panel (a) Average Δ% in EU Share of Foreign Purchases				
Total	**-0.60**	-0.57	**-1.27**	-1.23
	(1.30)	(1.25)	**(2.80)**	(2.73)
... of clean intermediate goods	**0.57**	0.55	**1.91**	1.86
	(0.34)	(0.33)	**(1.70)**	(1.66)
... of dirty intermediate goods	**-1.06**	-1.02	**-2.14**	-2.07
	(2.37)	(2.28)	**(3.59)**	(3.49)
Panel (b) Average Δ% in EU Share of Domestic Purchases				
Total	**0.04**	0.04	**0.10**	0.10
... of clean intermediate goods	**0.08**	0.08	**0.18**	0.18
... of dirty intermediate goods	**0.03**	0.03	**0.07**	0.07
Panel (c) Average Δ% in EU Domar Weights				
Total	**0.03**	0.03	**0.14**	0.14
	(0.19)	(0.19)	**(0.40)**	(0.39)
... of clean intermediate goods	**0.11**	0.10	**0.29**	0.28
	(0.09)	(0.09)	**(0.29)**	(0.28)
... of dirty intermediate goods	**-0.03**	-0.02	**0**	0
	(0.22)	(0.22)	**(0.44)**	(0.43)

Table 1: Policy-induced changes in EU-ETS shares (% of baseline). Panel (a) presents the mean percentage change across countries of the share EU purchases of intermediate inputs sourced from non-EU countries in EU total intermediate input purchases, with standard deviations (in parentheses) capturing the dispersion of country-specific changes around the mean. Panel (b) shows the mean percentage change of the share of intermediate inputs sourced domestically. Finally, Panel (c) reports the mean percentage change in EU sectoral sales, with the standard deviations (in parentheses) indicating the dispersion of sectoral changes around this average. Each value is considered under two scenarios: one in which the CBAM is determined endogenously (columns labeled ***Endog.***) and one in which it is exogenous (columns labeled *Exog.*). **Our main analysis focuses on the endogenous scenario (columns *Endog.*).**

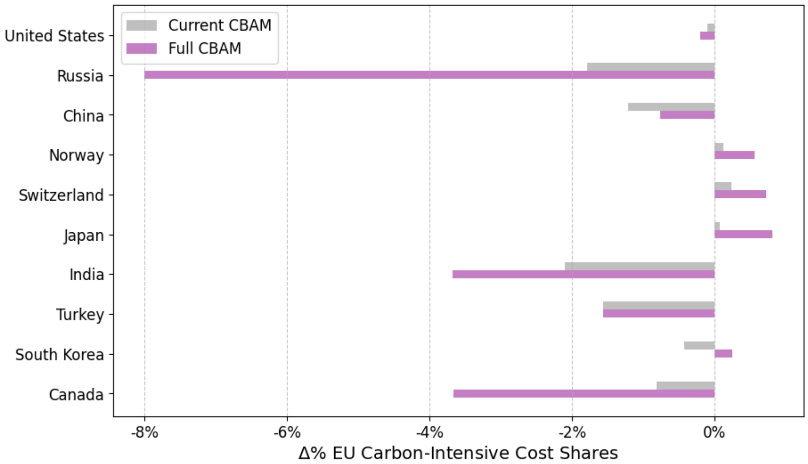
Exposure Index[15], with Ukraine being the most affected country, followed by South Africa, India, Russia, and China. All countries that are identified as highly exposed to the CBAM in the index experience a decline in their export share towards the European Union.

Figure 3 illustrates the heterogeneous impact of the CBAM on the Domar weights of European sectors, highlighting the 15 most affected industries across both carbon-intensive and non-carbon-intensive categories. The most substantial declines occur in carbon-intensive sectors — such as basic metals, chemical products, and fabricated metal products. In contrast, non-carbon-intensive sectors, which are not directly targeted by the current CBAM, experience marginal or modest gains. These gains arise from the complex substitution patterns along the supply chain and are captured by our model. As an illustration, consider *Coke and refined petroleum products* sector. When only a subset of sectors is targeted under the current CBAM, *Coke and refined petroleum products*, that is not subject to the wedge, act as a substitute for regulated inputs, experiencing an increase in its size. However, when the CBAM is extended to cover all sectors under the EU-ETS, including *Coke and refined petroleum products*, the effect is reversed and the competitive advantage of the sector vanishes. These indirect effects become increasingly significant as the elasticity of substitution increases, as shown in sensitivity checks in Appendix Figure A6.

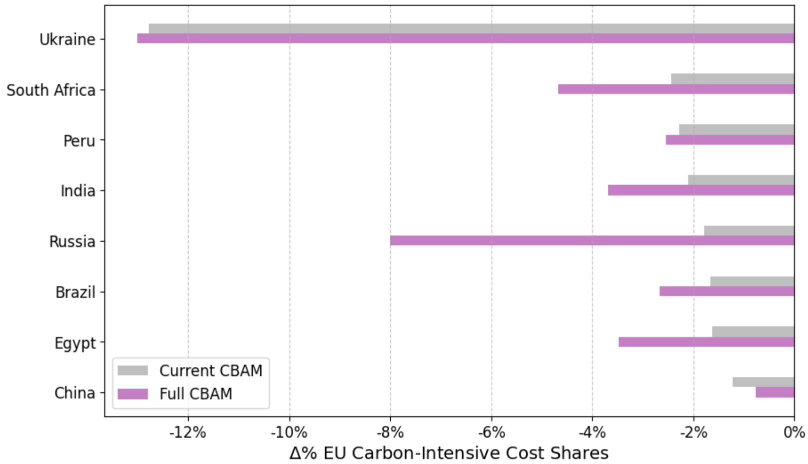
We now turn to the impact of CBAM on emissions, beginning with the emissions embodied in imports.

Emissions embodied in trade are calculated using the vector of production-based emissions and input-output multipliers. We borrow the definition from the OECD (Yamano and Guilhoto, 2020) and we adapt it to align with the structure of our model. The emissions embodied in European imports are given by the following vector $\mathbf{EEI}(EU) \in \mathbb{R}^{NJ}$ with entries corresponding to the emissions generated from the production of each good $j \in \mathcal{J}$ in every country $i \in \mathcal{N}$ embodied in European imports. In particular, the first equivalence in equation (17) corresponds to the OECD definition, while the subsequent equality restates

[15] https://www.worldbank.org/en/data/interactive/2023/06/15/relative-cbam-exposure-index



(a) 10 biggest exporters of polluting goods



(b) 10 most affected countries

Figure 2: Policy-induced changes in European shares of foreign purchases of dirty goods for selected countries (% of baseline level).

it in terms of our notation and modeling framework[16]:

$$\mathbf{EEI}(EU) \equiv \tilde{\boldsymbol{\rho}}(\mathbf{I}-\boldsymbol{\Omega})^{-1}\mathbf{X}_{EU}\mathbf{1} = \tilde{\boldsymbol{\rho}}(\mathbf{I}-\boldsymbol{\Omega})^{-1}\gamma\tilde{\boldsymbol{\Omega}}_{EU}diag(\boldsymbol{\Lambda})\mathbf{1}GNE \tag{17}$$

where $\tilde{\boldsymbol{\rho}} = diag(\tilde{\rho}_1^1, ..., \tilde{\rho}_N^J) \in \mathcal{M}(NJ \times NJ)$ is a diagonal matrix with entries $\tilde{\rho}_i^j \equiv e_i^j/p_i^j q_i^j \ \forall i \in \mathcal{N}, j \in \mathcal{J}$ corresponding to the tons of emissions per dollar of output in a given sector-country pair, $\tilde{\boldsymbol{\Omega}}_{EU} \in \mathcal{M}(NJ \times NJ)$ is the matrix of input-output coefficients, with non-zero entries only for European destination

[16] A more detailed derivation is left to the corresponding section in the Appendix A.2.

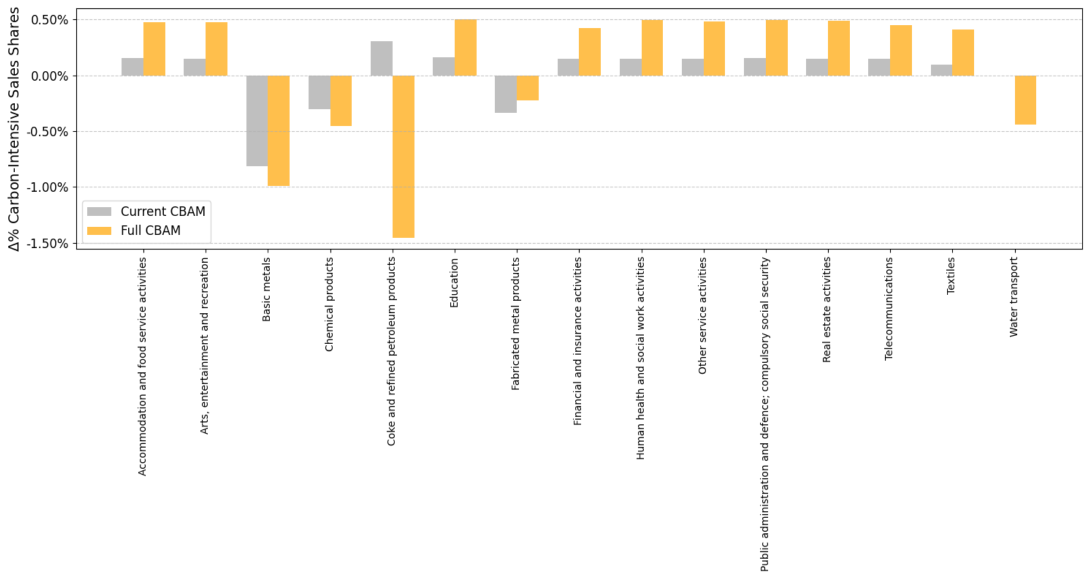


Figure 3: Policy-induced changes in European Domar weights of selected sectors (% of baseline level).

sectors, excluding intra-EU trade, $\mathbf{\Lambda} \in \mathbb{R}^{NJ}$ is the vector of Domar weights and GNE is the world Gross National Expenditure. The term $\gamma\tilde{\mathbf{\Omega}}_{EU} diag(\mathbf{\Lambda})\mathbf{1}GNE$ corresponds to the total value of European imports, expressed compactly as $\mathbf{X}_{EU}\mathbf{1}$, where $\mathbf{X}_{EU} \in \mathcal{M}(NJ \times NJ)$ is the matrix of trade flows between all country-sector pairs, with non-zero entries only for European destination sectors, again excluding intra-EU trade. The expression captures the total emissions embodied in European imports, including both emissions generated from the production of goods exported directly to the EU (emissions embodied in *direct* imports) and emissions generated throughout the supply chain (emissions from *indirect imports*), accounted for by the Leontief inverse $(\mathbf{I} - \mathbf{\Omega})^{-1}$. If we abstract from the upstream linkages by setting $\mathbf{\Omega} = \mathbf{0}$, only emissions embodied in *direct* imports remain, reflecting emissions from goods produced abroad and directly exported to the EU.

Table 2 presents the changes in emissions associated with European imports. Our results reported in Panel (a) show that CBAM leads to a 4.73% reduction in emissions embodied in direct imports, reaching almost 7% when only dirty intermediate goods are considered. When the indirect emissions are incorporated (Panel (b)), the magnitude of emissions reductions is attenuated but remains substantial: total emissions reduction under the current CBAM is 2.96%, compared to 5.19% under the full CBAM. This attenuation is expected. While the CBAM directly reduces imports of carbon-intensive goods explicitly covered by the adjustment mechanism – captured by the reduction in emissions embodied in direct imports – it simultaneously induces substitution towards non-targeted inputs. This effect propagates upstream through the supply network, increasing the demand for inputs along the supply chain, some of which are dirty, thereby raising indirect emissions. These upstream emissions fall outside the scope of the CBAM. As a consequence, the observed reduction in the carbon content of imports is smaller when these indirect channels are taken into account, which is a novel insight provided by our paper. Therefore, failing to account for these higher-order network effects leads to a significant overestimation of the effects of the CBAM.

Finally, Panel (c) reports changes in emissions leakage. In our framework, the leakage coincides with the change in emissions of countries that have not adopted a carbon market yet. Emissions leakage declines by 0.07% under the current CBAM and by 0.19% under the full CBAM. This confirms that carbon border adjustments contribute to containing emissions in countries with less stringent environmental regulations. Overall, our findings suggest that the policy contributes to the reduction of emissions leakage.

We are also able to decompose the total change in emissions embodied in European imports into two key components: a *technology* effect, i.e., capturing changes in emissions from production, and a *reallocation* effect, i.e., capturing changes in sourcing patterns across countries and sectors. A detailed derivation of this decomposition, expressed in terms of changes in cost shares and production-based emissions is provided in A.2. For our current purposes, it is sufficient to note that the *technology effect* corresponds to the changes in the vector $\tilde{\boldsymbol{\rho}}$ of emissions per dollar of output in equation (17), holding the structure of global production linkages constant. Unlike $\rho_i^j = t_i e_i^j / p_i^j q_i^j$ that is a fixed parameter of our model, $\tilde{\rho}_i^j = e_i^j / p_i^j q_i^j$ varies in response to changes in the input mix. Intuitively, this captures the reduction in the tons of emissions generated from production resulting from a shift toward cleaner inputs within existing production chains. By contrast, the *reallocation effect* stems from changes in the production network, captured by the Leontief inverse $(\mathbf{I} - \boldsymbol{\Omega})^{-1}$, and in the European imports, represented by $\mathbf{X}_{EU}$, holding production-based emissions fixed.

The corresponding Figure 4 illustrates this decomposition clearly. In all cases – whether total, clean, or dirty imports, and under both the current and full CBAM scenarios – the reallocation effect accounts for more than 50% of the

Variable	Current CBAM		Full CBAM	
	Endog.	*Exog.*	***Endog.***	*Exog.*
Panel (a) Δ% tons emissions embodied in direct imports				
Total	**-4.73**	-4.70	**-8.84**	-8.76
... of clean intermediate goods	**0.87**	0.85	**2.54**	2.48
... of dirty intermediate goods	**-6.84**	-6.69	**-13.12**	-12.84
Panel (b) Δ% tons emissions embodied in direct and indirect imports				
Total	**-2.96**	-2.90	**-5.19**	-5.08
... of clean intermediate goods	**0.91**	0.89	**2.62**	2.56
... of dirty intermediate goods	**-3.94**	-3.86	**-7.18**	-7.02
Panel (c) Δ% Emissions Leakage				
Total	**-0.07**	-0.07	**-0.19**	-0.18

Table 2: Policy-induced changes in Emissions Embodied in EU Imports and Emissions Leakage (% of baseline level). Each value is considered under two scenarios: one in which the CBAM is determined endogenously (columns labeled ***Endog.***) and one in which it is exogenous (columns labeled *Exog.*). **Our main analysis focuses on the endogenous scenario (columns *Endog.*).**

total change in emissions. This evidence underscores the dominant role of trade reallocation mechanisms and highlights the importance of tracking changes that occur across the production network in order to understand the environmental impact of border carbon adjustments. In conclusion, our results underscore the importance of adopting a supply-chain-wide perspective in both the evaluation and design of border carbon adjustments, thus emphasising the added value of an endogenous CBAM mechanism to ensure that its full emissions footprint is captured.

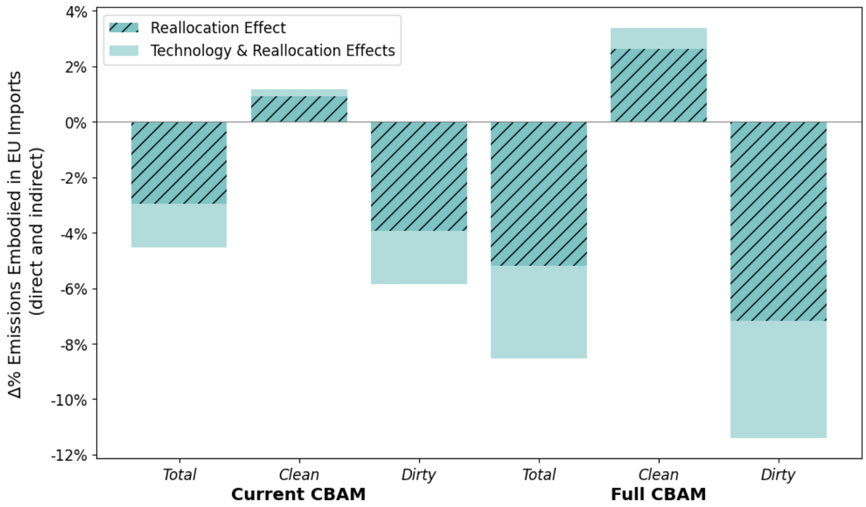


Figure 4: Decomposition of the change in Emissions Embodied in European Imports.

We close this section by examining the effects of the CBAM on real GNE. Table 3 reports the percentage changes in EU (Panel (a)) and extra-EU (Panel (b)) real gross national expenditures following the introduction of the CBAM. Under the current CBAM configuration, EU GNE slightly rises by 0.006%, while under the full CBAM scenario, the increase reaches 0.04%. This modest improvement in the EU GNE is driven by the reallocation of demand away from foreign carbon-intensive goods and towards domestic production. Given that trade deficits are fixed in the model, this translates into an increase in the price of domestic goods relative to foreign ones. This effect improves the EU's trade balance and raises GNE. Results are consistent with Flórez Mendoza, Reiter, and Stehrer (2024), who report a welfare gain of 0.016%. Despite the increase in GNE, real wages decline by 0.02% and 0.05% under the current and full CBAM scenarios, respectively. Panel (b) considers the effects on GNE in extra-EU countries. In these economies, the impact on GNE is modestly negative, with decreases of 0.008% under the current CBAM and 0.02% under the full CBAM scenario. Notably, the endogenous adjustment of the CBAM does not substantially alter the magnitude of the changes in real GNE and wages, which remain close to the scenario where the CBAM is exogenous.

Variable	**Current CBAM**		**Full CBAM**	
	Endog.	*Exog.*	***Endog.***	*Exog.*
Panel (a) Δ% EU Gross National Expenditure				
Total	**0.006**	0.006	**0.04**	0.04
… *Real Wages*	**-0.02**	-0.02	**-0.05**	-0.05
Panel (b) Δ% extra-EU Gross National Expenditure				
Total	**-0.008**	-0.008	**-0.02**	-0.02
… *Real Wages*	**-0.009**	-0.008	**-0.02**	-0.02

Table 3: Policy-induced changes in Gross National Expenditure (% of baseline level). Each value is considered under two scenarios: one in which the CBAM is determined endogenously (columns labeled ***Endog.***) and one in which it is exogenous (columns labeled *Exog.*). **Our main analysis focuses on the endogenous scenario (columns *Endog.*).**

The role of integration and technology.

Intuitively, the effect of the CBAM strongly depends both on the technology used in importing source countries as well as the integration of the EU in the global supply network. We now conduct two kinds of counterfactual exercises to shed some light on how these two dimensions influence the effects of the CBAM. In the first, to capture the effect of technology, we vary the output elasticity with respect to emissions, while in the second, we vary the integration of the EU in the global supply chain. In both types of exercises, we focus on the key outcome of our analysis — embodied emissions in EU imports.

First, to examine the effect of technology, we construct a counterfactual in which carbon intensities, captured with ρ_i^j, are halved relative to those observed at the baseline. The resulting scenario enables us to assess how the effects of CBAM respond to a counterfactual circumstance where the world's technology becomes cleaner.

Figure 5 shows the reduction in emissions embodied in EU imports—both direct and total—under two scenarios: the one with observed carbon intensities

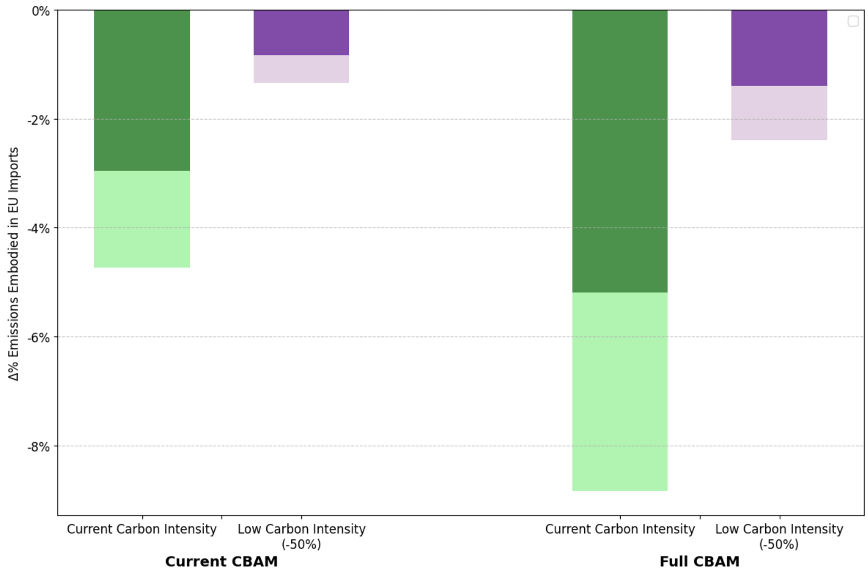
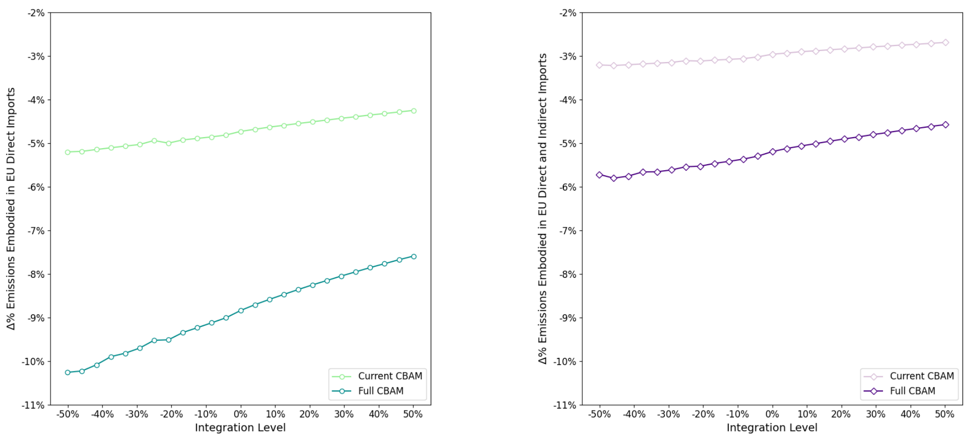


Figure 5: Policy-induced changes in Emissions Embodied in EU Imports under Current and Low-Carbon Intensity Scenarios (Percentages are computed with reference to the value of the corresponding embodied emissions (direct or total) under the scenario with current carbon intensities and no CBAM applied).

and a counterfactual in which the carbon intensity of production is halved across all country-sector pairs. Results are presented as percentage changes relative to the baseline. As expected, the impact of the CBAM on reducing embodied emissions weakens in a world where global production is less carbon-intensive, since the associated CBAM charges are lower. However, the reduction in effectiveness is more than proportional, highlighting the disproportionate influence of production technologies on the policy's impact.

Second, to assess the role of global supply chain integration, we conduct a counterfactual exercise that systematically alters the reliance on imported inputs. Specifically, for each EU importing sector, we vary the ratio of imported to domestic inputs, where a higher ratio reflects deeper integration of EU production into global supply chains. We then plot the impact of the CBAM on embodied emissions as a function of this ratio. This exercise is, therefore, informative about how the CBAM works under different levels of integration, while holding constant the relative sourcing pattern across foreign trade partners and sectors.

Figure 6 shows how emissions embodied in imports change following the introduction of the CBAM, relative to the baseline, as the degree of integration into global supply chains varies. The CBAM induces two types of substitution: towards domestic inputs and towards cleaner and untargeted foreign inputs. We find that when the EU economy is less integrated – that is, when sectors rely more on domestic rather than imported inputs – the CBAM leads to a stronger shift toward domestic sourcing. This reallocation results in a larger reduction in emissions embodied in imports, simply because a greater share of inputs originates within the EU and thus lies outside the CBAM's scope. As integration rises, the dependence on foreign inputs increases, diminishing the potential for substituting toward domestic inputs, and consequently weakening the emissions-reducing effect of the policy. Nevertheless, the CBAM continues to influence sourcing decisions, prompting a shift toward cleaner or exempt foreign goods, which partly offsets the reduced scope for domestic substitution. Although emissions embodied in imports still fall relative to the baseline, the overall reduction is smaller, highlighting the dominant role of domestic substitution in driving the CBAM's impact. Notably, the effect of integration on CBAM effectiveness is less than proportional.



(a) Emissions embodied in direct imports

(b) Emissions embodied in direct and indirect imports

Figure 6: Policy-induced changes in Emissions Embodied in EU Imports under varying levels of trade integration (Percentages are computed with reference to the value of the corresponding embodied emissions (direct or total) under the scenario with the current level of trade integration (0% change) and no CBAM applied).

Our counterfactual exercises therefore show that cleaner global production reduces the CBAM's impact in a more-than-proportional way, underscoring the importance of the technology dimension. A higher supply chain integration weakens the policy's effectiveness, as the scope for substituting toward domestic inputs shrinks. Still, the integration in the global supply chain affects the effects of CBAM, albeit to a lesser extent than the technology dimension. We, however, note that these two effects are interrelated, as the EU producers in general tend to source more from destinations using more carbon-intensive technologies.

6. CONCLUSION

This paper offers a comprehensive assessment of the economic and environmental implications of the EU's CBAM with a multi-country, multi-sector general equilibrium model with global input-output linkages. By endogenizing both the CBAM and ETS allowances' prices, our model captures the feedback mechanisms that arise between national climate policies and international trade patterns. Results show that CBAM induces a reallocation of purchases towards domestic and foreign clean inputs and significantly reduces emissions embodied in imports. Crucially, our findings highlight the importance of accounting for supply chain reallocation effects: while the CBAM substantially reduces direct emissions embodied in imports, a non-negligible share of emissions comes from upstream inputs and remains outside the policy scope. Overall, the paper contributes to the growing literature on the problem of international coordination by open economies in the presence of climate change. In particular, our framework offers a valuable tool for policymakers to design across-the-border policies that account for the complex interdependencies of global supply chains.

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A. Appendix

A.1 Data

The following section describes the data used in the quantitative analysis. The list of considered countries includes: Argentina, Australia, Bangladesh, Brazil, Canada, Chile, China, Colombia, Costa Rica, Cote d'Ivoire, Egypt, European Union, Iceland, India, Indonesia, Israel, Japan, Malaysia, Morocco, Mexico, New Zealand, Nigeria, Norway, Peru, Philippines, Russia, South Africa, South Korea, Switzerland, Turkey, Ukraine, United States and an aggregate Rest of the World[17]. The list of sectors is reported in Table A1, where we aggregate the two sectors of "Other service activities" and "Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use" under the 44th sector in order to eliminate zero domestic production shares from the Input-Output table.

- **Input-Output Tables** To calibrate the model on the year 2018, we use the 2021 release of the OECD Inter-Country Input-Output tables (Cimper, Zürcher, and Han, 2021), collecting data on expenditures in intermediate inputs X_{ni}^{kj} and final goods F_{ni}^{j}, gross output GO_i^j and value-added VA_i^j. Concerning final consumption, we ignore Gross Fixed Capital Formation and Changes in Inventories and Valuables. Values are reported in millions of U.S. dollars at current prices and the flows of goods and services within and across countries are directly mapped to the cost shares in intermediate goods $\tilde{\omega}_{ni}^{kj} = X_{ni}^{kj} / \sum_{n \in \mathcal{N}} \sum_{j \in \mathcal{J}} X_{ni}^{kj}$ and the shares of final consumption $\alpha_i^j = \sum_{n \in \mathcal{N}} F_{ni}^j / \sum_{n \in \mathcal{N}} \sum_{j \in \mathcal{J}} F_{ni}^j$. Finally, the shares of value added are computed as $\beta_i^j = VA_i^j / GO_i^j$. We have a unique country-sector pair (Chile - Motor vehicles, trailers and semi-trailers) with a gross output equal to 0, which can be either due to missing observations or zero production in that sector and country. Since these cases generate computational issues, we input a value of 1 to this observation.

- **Tariffs** Bilateral tariffs for the year 2018 are collected from the United Na-

[17] Due to the unavailability of data on emissions and emissions pricing, we move the following countries to the "Rest of the World" category in our analysis: Brunei, Cameroon, Hong Kong, Jordan, Kazakhstan, Cambodia, Laos, Myanmar, Pakistan, Saudi Arabia, Senegal, Singapore, Thailand, Tunisia, Taiwan, and Vietnam.

tions Statistical Division-Trade Analysis and Information System (UNCTAD-TRAINS). We consider effective applied rates at 6-digit of the Harmonised System and build the weighted average tariff corresponding to our sectoral classification, using the associated import values. For the cases in which a single HS6 code corresponds to more than one ISIC 2-digit code, we impute the same share of import values to all the ISIC categories. Finally, when tariff data for the year 2018 were not available, we substitute this value with the closest one available, searching for the three previous years.

- **Emissions and carbon prices** Emissions from production are taken from the OECD Environmental Statistics database. We consider Scope 1 Emissions for each country-sector pair E_i^j, including all direct GHG emissions measured in million tonnes of CO_2 equivalent. For the European Union, Iceland and Norway we employ a distinct approach. Emissions data are taken from the European Union Transaction Log (EUTL), recording all transactions carried out under the EU-ETS, with information on each entity covered by the system. The EUTL provides granula, entity-level information on verified emissions and the volume of freely allocated allowances on an annual basis. We aggregate these data at the selected sectoral level and adjust the reported emissions by deducting those covered by freely allocated allowances. In order to build the emissions elasticity ρ_i^j, these values are multiplied by the corresponding country's Effective Carbon Rate (ECR), converted into USD using the OECD exchange rate for the year 2018. Effective Carbon Rates represent the total price t_i of one ton of CO_2 emissions as the sum of carbon taxes, specific taxes on energy use and the price of tradable emission permits. Emission elasticities are then computed as $\rho_i^j = t_i E_i^j / GO_i^j$.

Industry Description	OECD Code	ISIC Rev.4	ETS	CBAM
Agriculture, hunting, forestry	A01_02	01, 02	0	0
Fishing and aquaculture	A03	03	0	0
Mining and quarrying, energy producing products	B05_06	05, 06	1	0
Mining and quarrying, non-energy producing products	B07_08	07, 08	1	1
Mining support service activities	B09	09	1	0
Food products, beverages and tobacco	C10_12	10 to 12	1	0
Textiles, textile products, leather and footwear	C13_15	13 to 15	0	0
Wood and products of wood and cork	C16	16	1	0
Paper products and printing	C17_18	17, 18	1	0
Coke and refined petroleum products	C19	19	1	0
Chemical and chemical products	C20	20	1	1
Pharmaceuticals, medicinal chemical and botanical products	C21	21	1	0
Rubber and plastics products	C22	22	1	0
Other non-metallic mineral products	C23	23	1	1
Basic metals	C24	24	1	1
Fabricated metal products	C25	25	1	1
Computer, electronic and optical equipment	C26	26	1	0
Electrical equipment	C27	27	1	0
Machinery and equipment, nec	C28	28	0	0
Motor vehicles, trailers and semi-trailers	C29	29	1	0
Other transport equipment	C30	30	1	0
Manufacturing nec; repair and installation of machinery and equipment	C31_33	31 to 33	1	0
Electricity, gas, steam and air conditioning supply	D	35	1	1
Water supply; sewerage, waste management and remediation activities	E	36 to 39	0	0
Construction	F	41 to 43	1	0
Wholesale and retail trade; repair of motor vehicles	G	45 to 47	1	0
Land transport and transport via pipelines	H49	49	0	0
Water transport	H50	50	0	0
Air transport	H51	51	0	0
Warehousing and support activities for transportation	H52	52	1	0
Postal and courier activities	H53	53	0	0
Accommodation and food service activities	I	55, 56	0	0
Publishing, audiovisual and broadcasting activities	J58_60	58 to 60	0	0
Telecommunications	J61	61		
IT and other information services	J62_63	62, 63	0	0
Financial and insurance activities	64 to 66	1	0	
Real estate activities	L	68	1	0
Professional, scientific and technical activities	M	69 to 75	1	0
Administrative and support services	N	77 to 82	1	0
Public administration and defence; compulsory social security	O	84	0	0
Education	P	85		
Human health and social work activities	Q	86 to 88	0	0
Arts, entertainment and recreation	R	90 to 93	0	0
Other service activities + Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	S, T	94 to 98	0	0

Table A1: The table lists the sectoral classification in our analysis, distinguishing whether a sector is covered by the ETS (*ETS*=1), CBAM(*CBAM*=1) or both.

Marginal cost

LEMMA A.1. — *The marginal cost of a firm is given by:*

$$mc_i^j = \frac{1}{(A_i^j)^{1-\rho_i^j}} \left[w_i^{\beta_i^j} (P_i^j)^{1-\beta_i^j} \right]^{1-\rho_i^j} [t_i(1-\epsilon_i^j)]^{\rho_i^j} \tag{18}$$

Proof. Each producer solves the following cost minimisation problem:

$$\min_{l_i^j, e_i^j, z_{1i}^{1j}, \ldots, z_{Ni}^{Jj}} TC_i^j = w_i l_i^j + \sum_{n \in \mathcal{N}} \sum_{k \in \mathcal{J}} p_{ni}^{kj} z_{ni}^{kj} + t_i(1-\epsilon_i^j) e_i^j$$

$$\text{s.t. } q_i^j \leq \Upsilon_i^j \left[A_i^j (l_i^j)^{\beta_i^j} \left(\sum_{n \in \mathcal{N}} \sum_{k \in \mathcal{J}} (\iota_{ni}^{kj})^{\frac{1}{\theta}} (z_{ni}^{kj})^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}(1-\beta_i^j)} \right]^{1-\rho_i^j} [e_i^j]^{\rho_i^j}$$

The Lagrangian is equal to:

$$\mathcal{L}(l_i^j, e_i^j, z_{1i}^{1j}, \ldots, z_{Ni}^{Jj}, \lambda) = w_i l_i^j + \sum_{n \in \mathcal{N}} \sum_{k \in \mathcal{J}} p_{ni}^{kj} z_{ni}^{kj} + t_i(1-\epsilon_i^j) e_i^j +$$

$$+\lambda \left\{ q_i^j - \Upsilon_i^j \left[A_i^j (l_i^j)^{\beta_i^j} \left(\sum_{n \in \mathcal{N}} \sum_{k \in \mathcal{J}} (\iota_{ni}^{kj})^{\frac{1}{\theta}} (z_{ni}^{kj})^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}(1-\beta_i^j)} \right]^{1-\rho_i^j} [e_i^j]^{\rho_i^j} \right\}$$

and the FONCs, which are also sufficient given the assumed Cobb-Douglas production function, are:

$$\begin{cases} \frac{\partial \mathcal{L}}{\partial l_i^j} = w_i - \lambda(1-\rho_i^j)\beta_i^j \frac{q_i^j}{l_i^j} = 0 \\ \frac{\partial \mathcal{L}}{\partial e_i^j} = t_i(1-\epsilon_i^j) - \lambda \rho_i^j \frac{q_i^j}{e_i^j} = 0 \\ \forall n, k: \quad \frac{\partial \mathcal{L}}{\partial z_{ni}^{kj}} = \frac{\partial \mathcal{L}}{\partial M_i^j} \frac{\partial M_i^j}{\partial z_{ni}^{kj}} = p_{ni}^{kj} - \lambda \left[(1-\beta_i^j)(1-\rho_i^j) \frac{q_i^j}{M_i^j} \right] \left[(\iota_{ni}^{kj})^{\frac{1}{\theta}} (z_{ni}^{kj})^{\frac{\theta-1}{\theta}-1} (M_i^j)^{\frac{1}{\theta}} \right] = 0 \\ \frac{\partial \mathcal{L}}{\partial \lambda} = q_i^j - \Upsilon_i^j \left[A_i^j (l_i^j)^{\beta_i^j} (M_i^j)^{1-\beta_i^j} \right]^{1-\rho_i^j} [e_i^j]^{\rho_i^j} = 0 \end{cases}$$

By taking the ratio of any two intermediate inputs and using the CES aggregate for materials M_i^j, the optimal amount of each intermediate input z_{ni}^{kj} is given by:

$$z_{ni}^{kj} = \iota_{ni}^{kj} \left(\frac{p_{ni}^{kj}}{P_i^j} \right)^{-\theta} M_i^j \tag{19}$$

with $P_i^j \equiv \left(\sum_{n \in \mathcal{N}} \sum_{k \in \mathcal{J}} \iota_{ni}^{kj} (p_{ni}^{kj})^{1-\theta} \right)^{\frac{1}{1-\theta}}$ being the price index of the intermediate goods.

Using (16) and the FOC for the intermediate inputs:

$$M_i^j = \lambda (1 - \beta_i^j)(1 - \rho_i^j) q_i^j (P_i^j)^{-1}$$

and using the expression for λ from the FOC for the labour l_i^j:

$$M_i^j = \frac{1 - \beta_i^j}{\beta_i^j} \frac{w_i}{P_i^j} l_i^j$$

Moreover, from the FOCs for labor and emissions we get:

$$e_i^j = \frac{\rho_i^j}{\beta_i^j (1 - \rho_i^j)} \frac{w_i}{t_i (1 - \epsilon_i^j)} l_i^j$$

Plugging the above equations for M_i^j and l_i^j into the production function and solving for l_i^j, M_i^j and e_i^j, the conditional input demand functions are given by:

$$l_i^j = \frac{1}{\Upsilon_i^j} \frac{q_i^j}{(A_i^j)^{1-\rho_i^j}} \left(\frac{\beta_i^j}{1 - \beta_i^j} \frac{P_i^j}{w_i} \right)^{(1-\beta_i^j)(1-\rho_i^j)} \left(\frac{\beta_i^j (1 - \rho_i^j)}{\rho_i^j} \frac{t_i (1 - \epsilon_i^j)}{w_i} \right)^{\rho_i^j} =$$

$$= \beta_i^j (1 - \rho_i^j) \frac{q_i^j}{(A_i^j)^{1-\rho_i^j}} \left[w_i^{\beta_i^j (1-\rho_i^j) - 1} \left(P_i^j \right)^{(1-\beta_i^j)(1-\rho_i^j)} [t_i (1 - \epsilon_i^j)]^{\rho_i^j} \right] \tag{20}$$

$$M_i^j = \frac{q_i^j}{\Upsilon_i^j (A_i^j)^{1-\rho_i^j}} \left(\frac{\beta_i^j}{1 - \beta_i^j} \frac{P_i^j}{w_i} \right)^{(1-\beta_i^j)(1-\rho_i^j)-1} \left(\frac{\beta_i^j (1 - \rho_i^j)}{\rho_i^j} \frac{t_i (1 - \epsilon_i^j)}{w_i} \right)^{\rho_i^j}$$

$$= (1-\beta_i^j)(1-\rho_i^j)\frac{q_i^j}{(A_i^j)^{1-\rho_i^j}}\left[w_i^{\beta_i^j(1-\rho_i^j)}\left(P_i^j\right)^{(1-\beta_i^j)(1-\rho_i^j)-1}[t_i(1-\epsilon_i^j)]^{\rho_i^j}\right] \tag{21}$$

$$e_i^j = \frac{q_i^j}{\Upsilon_i^j(A_i^j)^{1-\rho_i^j}}\left(\frac{\beta_i^j}{1-\beta_i^j}\frac{P_i^j}{w_i}\right)^{(1-\beta_i^j)(1-\rho_i^j)}\left(\frac{\beta_i^j(1-\rho_i^j)}{\rho_i^j}\frac{t_i(1-\epsilon_i^j)}{w_i}\right)^{\rho_i^j-1}$$

$$= \rho_i^j\frac{q_i^j}{(A_i^j)^{1-\rho_i^j}}\left[w_i^{\beta_i^j(1-\rho_i^j)}\left(P_i^j\right)^{(1-\beta_i^j)(1-\rho_i^j)}[t_i(1-\epsilon_i^j)]^{\rho_i^j-1}\right] \tag{22}$$

Taking the derivative of the total cost function with respect to q_i^j, computed at the optimal input combination, provides the marginal cost of the input bundle, given by:

$$mc_i^j \equiv \frac{\partial TC_i^j}{\partial q_i^j} = \frac{\partial(w_i l_i^j + P_i^j M_i^j + t_i e_i^j)}{\partial q_i^j} =$$

$$= \left[\beta_i^j(1-\rho_i^j) + (1-\beta_i^j)(1-\rho_i^j) + \rho_i^j\right]\left[\frac{1}{(A_i^j)^{1-\rho_i^j}}\left[w_i^{\beta_i^j}(P_i^j)^{1-\beta_i^j}\right]^{1-\rho_i^j}[t_i(1-\epsilon_i^j)]^{\rho_i^j}\right] =$$

$$= \frac{1}{(A_i^j)^{1-\rho_i^j}}\left[w_i^{\beta_i^j}(P_i^j)^{1-\beta_i^j}\right]^{1-\rho_i^j}[t_i(1-\epsilon_i^j)]^{\rho_i^j}$$

.

Steady state and normalisation We define the steady state as the combination of equilibrium prices and quantities in an undistorted economy with no wedges, where $(1-\epsilon_n^k)^{\rho_n^k}(A_n^k)^{-(1-\rho_n^k)} = 1 \quad \forall i,n \in \mathcal{N}\ j,k \in \mathcal{J}$. From Lemma A.2. and the pricing rule we have:

$$p_i^j = mc_i^j = \left[(A_i^j)^{-(1-\rho_i^j)} w_i^{\beta_i^j(1-\rho_i^j)}(P_i^j)^{(1-\beta_i^j)(1-\rho_i^j)}[t_i(1-\epsilon_i^j)]^{\rho_i^j}\right]$$

Taking its logs and evaluating it at the steady-state:

$$\log p_i^j = \beta_i^j(1-\rho_i^j)\log w_i + (1-\beta_i^j)(1-\rho_i^j)\log\left(\sum_{n\in\mathcal{N}}\sum_{k\in\mathcal{J}}\iota_{ni}^{kj}(p_n^k)^{1-\theta}\right)^{\frac{1}{1-\theta}} + \rho_i^j\log t_i$$

And the system of equations is solved for $p_i^j = w_i = t_i = 1 \quad \forall i, j$.

Comparative Statics We provide comparative statics that offer a first-order approximation of the effect of the CBAM on trade across sectors, welfare, and emissions. To account for the CBAM endogeneity, we proceed as follows. We define the steady state of the economy as one with no trade wedges. We write the tariff component of the price wedge on sectoral trade as $\tilde{\tau}_{ni}^{kj} = (1+\kappa_{ni}^{kj}+h_{ni}^{kj})$, where h_{ni}^{kj} denotes the CBAM imposed by country i on imports from sector k in country n. In the steady state, both κ_{ni}^{kj} and h_{ni}^{kj} are equal to zero. To capture the marginal impact of introducing the CBAM, we take the derivative of the relevant outcome variable with respect to h_{ni}^{kj} evaluated at the steady state. When constructing the first-order approximation of the CBAM's effect, we incorporate the feedback that the additional tariff has on emission prices – and consequently on the actual CBAM level – using the definition of the CBAM tariff in (7).

We start by establishing two important lemmas that underpin the analysis. These results provide the analytical structure necessary to understand how the introduction of the additional carbon tariff propagates and affects intermediate input prices and how the CBAM tariff adjusts endogenously to shifts in carbon prices.

Lemma A.2. — ***(Prices)*** *For a shock to the trade costs, the change in the price of intermediate inputs in the steady state is:*

$$\frac{\partial \log \mathbf{p}}{\partial h_{ls}^{qr}} = (\mathbf{I}-\boldsymbol{\gamma}\boldsymbol{\Pi}')^{-1}\left[\boldsymbol{\beta}(\mathbf{I}-\boldsymbol{\rho})\frac{\partial \log \mathbf{w}}{\partial h_{ls}^{qr}} + \boldsymbol{\rho}\frac{\partial \log \mathbf{t}}{\partial h_{ls}^{qr}} + \boldsymbol{\gamma} diag^{-1}\left(\boldsymbol{\Pi}'\mathbf{e}_{2(l-1)+q}\mathbf{e}'_{2(s-1)+r}\right)\right] \tag{23}$$

Proof. Consider first the price of intermediate inputs and the pricing rule. In equilibrium:

$$p_n^k = mc_n^k = (A_n^k)^{-(1-\rho_n^k)} w_n^{\beta_n^k(1-\rho_n^k)} (P_n^k)^{(1-\beta_n^k)(1-\rho_n^k)} [t_n(1-\epsilon_n^k)^{\rho_n^k}]$$

Taking its logarithm:

$$\log p_n^k = -(1-\rho_n^k)\log A_n^k + \beta_n^k(1-\rho_n^k)\log w_n + (1-\beta_n^k)(1-\rho_n^k)\log P_n^k + \rho_n^k \log[t_n(1-\epsilon_n^k)]$$

Given our modelling assumptions, the CBAM enters as an additional tariff, as shown in (6). Thus, we now consider a marginal increase in trade wedges, represented by an arbitrarily small positive h_{ls}^{qr}, and derive the percentage change in intermediate input prices in response to the shock. Differentiating with respect to h_{ls}^{qr} and evaluating it at the steady-state:

$$\frac{\partial \log p_n^k}{\partial h_{ls}^{qr}} = \beta_n^k(1-\rho_n^k)\frac{\partial \log w_n}{\partial h_{ls}^{qr}} + (1-\beta_n^k)(1-\rho_n^k)\frac{\partial \log P_n^k}{\partial h_{ls}^{qr}} + \rho_n^k \frac{\partial \log t_n}{\partial h_{ls}^{qr}} \tag{24}$$

where from the definition of the price index $P_n^k = \left(\sum_{m\in\mathcal{N}}\sum_{h\in\mathcal{J}} \iota_{mn}^{hk}(p_{mn}^{hk})^{1-\theta}\right)^{\frac{1}{1-\theta}}$, we have:

$$\frac{\partial \log P_n^k}{\partial h_{ls}^{qr}} = \frac{1}{\sum_{m\in\mathcal{N}}\sum_{h\in\mathcal{J}} \iota_{mn}^{hk}(p_{mn}^{hk})^{1-\theta}} \sum_{m\in\mathcal{N}}\sum_{h\in\mathcal{J}} \iota_{mn}^{hk}(p_{mn}^{hk})^{1-\theta}\frac{\partial \log p_{mn}^{hk}}{\partial h_{ls}^{qr}}$$

which in steady-state becomes:

$$\frac{\partial \log P_n^k}{\partial h_{ls}^{qr}} = \sum_{m\in\mathcal{N}}\sum_{h\in\mathcal{J}} \iota_{mn}^{hk}\frac{\partial \log p_m^h}{\partial h_{ls}^{qr}} + \sum_{m\in\mathcal{N}}\sum_{h\in\mathcal{J}} \iota_{mn}^{hk}\frac{\partial \log \tau_{mn}^{hk}}{\partial h_{ls}^{qr}}$$

where:

$$\frac{\partial \log \tau_{mn}^{hk}}{\partial h_{ls}^{qr}} = \frac{\partial h_{mn}^{hk}}{\partial h_{ls}^{qr}} = 1_{ls=mn}\cdot 1_{qr=hk} \tag{25}$$

Defining $\mathbf{\Pi} \in \mathcal{M}(NJ, NJ)$ the matrix with entries ι_{ni}^{kj} and with $\mathbf{p} \in \mathbb{R}^{NJ}$ the vector of prices p_i^j, in matrix notation we have:

$$\frac{\partial \log P_n^k}{\partial h_{ls}^{qr}} = \mathbf{e'}_{2(n-1)+k}\mathbf{\Pi}'\frac{\partial \log \mathbf{p}}{\partial h_{ls}^{qr}} + \mathbf{e'}_{2(n-1)+k}diag^{-1}\left(\mathbf{\Pi}'\mathbf{e}_{2(l-1)+q}\mathbf{e'}_{2(s-1)+r}\right) \tag{26}$$

and the derivative of the vector of log prices can be rewritten as:

$$\frac{\partial \log \mathbf{p}}{\partial h_{ls}^{qr}} = \boldsymbol{\beta}(\mathbf{I}-\boldsymbol{\rho})\frac{\partial \log \mathbf{w}}{\partial h_{ls}^{qr}}+\boldsymbol{\rho}\frac{\partial \log \mathbf{t}}{\partial h_{ls}^{qr}}+\boldsymbol{\gamma}\boldsymbol{\Pi}'\frac{\partial \log \mathbf{p}}{\partial h_{ls}^{qr}}+\boldsymbol{\gamma} diag^{-1}\left(\boldsymbol{\Pi}'\mathbf{e}_{2(l-1)+q}\mathbf{e}'_{2(s-1)+r}\right)$$

where $\boldsymbol{\rho} = diag(\rho_1^1, \rho_1^2, ..., \rho_N^J)' \in \mathcal{M}(NJ, NJ)$, $\boldsymbol{\beta} = diag(\beta_1^1, \beta_1^2, ..., \beta_N^J)' \in \mathcal{M}(NJ, NJ)$, $\boldsymbol{\gamma} = (\mathbf{I}-\boldsymbol{\beta})(\mathbf{I}-\boldsymbol{\rho}) \in \mathcal{M}(NJ, NJ)$, $\mathbf{w} = (w_1, ..., w_N)' \otimes \mathbf{1}_J \in \mathbb{R}^{NJ}$ and $\mathbf{t} = (t_1, ..., t_N)' \otimes \mathbf{1}_J$[18]. Thus:

$$\frac{\partial \log \mathbf{p}}{\partial h_{ls}^{qr}} = (\mathbf{I}-\boldsymbol{\gamma}\boldsymbol{\Pi}')^{-1}\left[\boldsymbol{\beta}(\mathbf{I}-\boldsymbol{\rho})\frac{\partial \log \mathbf{w}}{\partial h_{ls}^{qr}}+\boldsymbol{\rho}\frac{\partial \log \mathbf{t}}{\partial h_{ls}^{qr}}+\boldsymbol{\gamma} diag^{-1}\left(\boldsymbol{\Pi}'\mathbf{e}_{2(l-1)+q}\mathbf{e}'_{2(s-1)+r}\right)\right]$$

And in the special case where $\beta_i^j = \beta,\ \rho_i^j = \rho\ \forall i, j$:

$$\frac{\partial \log \mathbf{p}}{\partial h_{ls}^{qr}} = (\mathbf{I}-\gamma\boldsymbol{\Pi}')^{-1}\left[\beta(1-\rho)\frac{\partial \log \mathbf{w}}{\partial h_{ls}^{qr}}+\rho\frac{\partial \log \mathbf{t}}{\partial h_{ls}^{qr}}+\gamma diag^{-1}\left(\boldsymbol{\Pi}'\mathbf{e}_{2(l-1)+q}\mathbf{e}'_{2(s-1)+r}\right)\right]$$

Lemma A.3. — ***(CBAM)*** *For a shock to the trade cost, the first-order approximation around the steady-state of the change in the CBAM wedge applied on imports from sector q, country l and directed towards sector r in country s is:*

$$dCBAM_{ls}^{qr} = (\rho_l^q)^2\left(\frac{\partial \log t_s}{\partial h_{ls}^{qr}} - \frac{\partial \log t_l}{\partial h_{ls}^{qr}}\right) \tag{27}$$

Proof. Consider the change in the CBAM wedge, focusing on the more general case in which $CBAM_{ls}^{qr} = \rho_l^q\frac{t_s}{t_l}$. To a first-order:

$$dCBAM_{ls}^{qr} = d\left(\rho_l^q\frac{t_s}{t_l}\right) = \frac{\partial\left(\rho_l^q\frac{t_s}{t_l}\right)}{\partial h_{ls}^{qr}}\left(\rho_l^q\frac{t_s}{t_l} + d\left(\rho_l^q\frac{t_s}{t_l}\right)\right) =$$

[18] $\otimes$ denotes the Kronecker product.

$$= \frac{\frac{\partial\left(\rho_l^q \frac{t_s}{t_l}\right)}{\partial h_{ls}^{qr}} \rho_l^q \frac{t_s}{t_l}}{1 - \frac{\partial\left(\rho_l^q \frac{t_s}{t_l}\right)}{\partial h_{ls}^{qr}}}$$

which, for small shocks, is well approximated by:

$$dCBAM_{ls}^{qr} = \frac{\partial\left(\rho_l^q \frac{t_s}{t_l}\right)}{\partial h_{ls}^{qr}} \rho_l^q \frac{t_s}{t_l} = \rho_l^q \frac{t_s}{t_l} \left(\rho_l^q \frac{(\partial t_s/\partial h_{ls}^{qr})t_l - (\partial t_l/\partial h_{ls}^{qr})t_s}{t_l^2}\right)$$

Evaluating it at the steady-state:

$$dCBAM_{ls}^{qr} = (\rho_l^q)^2 \left(\frac{\partial \log t_s}{\partial h_{ls}^{qr}} - \frac{\partial \log t_l}{\partial h_{ls}^{qr}}\right)$$

With these components in place, we can now characterise the adjustment in cost shares, welfare and emissions embodied in imports resulting from the introduction of the CBAM.

Proposition A.1. — ***(Cost Shares)*** *The first-order approximation around the steady state of the change in the cost shares following the introduction of the CBAM is given by:*

$$\begin{aligned} d\log\tilde{\omega}_{ni}^{kj} = (1-\theta) \Bigg[&(\rho_n^k + dCBAM_{ni}^{kj}) + (1-\beta_n^k)(1-\rho_n^k) \sum_{l\in\mathcal{N}} \sum_{s\in\mathcal{N}} \sum_{q\in\mathcal{J}} \sum_{r\in\mathcal{J}} \psi_{ns}^{kr} \iota_{ls}^{qr} (\rho_l^q + dCBAM_{ls}^{qr}) + \\ &- \sum_{l\in\mathcal{N}} \sum_{s\in\mathcal{N}} \sum_{q\in\mathcal{J}} \sum_{r\in\mathcal{J}} \psi_{is}^{jr} \iota_{ls}^{qr} (\rho_l^q + dCBAM_{ls}^{qr}) \Bigg] + \\ +(1-\theta) \sum_{l\in\mathcal{N}} \sum_{s\in\mathcal{N}} \sum_{q\in\mathcal{J}} \sum_{r\in\mathcal{J}} \Bigg[&\mathbf{e}'_{2(n-1)+k} (\mathbf{I} - \gamma\mathbf{\Pi}')^{-1} \left(\beta(1-\rho)\frac{\partial \log \mathbf{w}}{\partial h_{ls}^{qr}} + \rho \frac{\partial \log \mathbf{t}}{\partial h_{ls}^{qr}}\right) - \\ &\mathbf{e}'_{2(i-1)+j} (\mathbf{I} - \gamma\mathbf{\Pi}')^{-1} \left(\beta(1-\rho)\frac{\partial \log \mathbf{w}}{\partial h_{ls}^{qr}} + \rho \frac{\partial \log \mathbf{t}}{\partial h_{ls}^{qr}}\right) \Bigg] (\rho_l^q + dCBAM_{ls}^{qr}) \end{aligned} \quad (28)$$

where $dCBAM_{ls}^{qr}$ is given by (27).

Proof. Consider the cost shares $\tilde{\omega}_{ni}^{kj}$. In equilibrium, from (19) and the pricing rule we have:

$$\tilde{\omega}_{ni}^{kj} = \iota_{ni}^{kj}(p_n^k \tau_{ni}^{kj})^{1-\theta}(P_i^j)^{-(1-\theta)}$$

Taking its logarithm:

$$\log \tilde{\omega}_{ni}^{kj} = \log \iota_{ni}^{kj} + (1-\theta)\left[\log p_n^k + \log \tau_{ni}^{kj} - logP_i^j\right]$$

and then differentiating with respect to h_{ls}^{qr} and evaluating it at the steady-state:

$$\frac{\partial \log \tilde{\omega}_{ni}^{kj}}{\partial h_{ls}^{qr}} = (1-\theta)\left[\frac{\partial \log p_n^k}{\partial h_{ls}^{qr}} + \frac{\partial \log \tau_{ni}^{kj}}{\partial h_{ls}^{qr}} - \frac{\partial \log P_i^j}{\partial h_{ls}^{qr}}\right] =$$

$$= (1-\theta)\left[1_{ls=ni} \cdot 1_{qr=kj} + \beta_n^k(1-\rho_n^k)\frac{\partial \log w_n}{\partial h_{ls}^{qr}} + \rho_n^k \frac{\partial \log t_n}{\partial h_{ls}^{qr}} + \right.$$

$$+(1-\beta_n^k)(1-\rho_n^k)\ \mathbf{e'}_{2(n-1)+k}\left(\mathbf{\Pi'}\frac{\partial \log \mathbf{p}}{\partial h_{ls}^{qr}} + diag^{-1}\left(\mathbf{\Pi'}\mathbf{e}_{2(l-1)+q}\mathbf{e'}_{2(s-1)+r}\right)\right) +$$

$$\left. -\mathbf{e'}_{2(i-1)+j}\left(\mathbf{\Pi'}\frac{\partial \log \mathbf{p}}{\partial h_{ls}^{qr}} + diag^{-1}\left(\mathbf{\Pi'}\mathbf{e}_{2(l-1)+q}\mathbf{e'}_{2(s-1)+r}\right)\right)\right]$$

where $\frac{d \log \mathbf{p}}{d \log h_{ls}^{qr}}$ is given by (23). Thus:

$$\frac{\partial \log \tilde{\omega}_{ni}^{kj}}{\partial h_{ls}^{qr}} = (1-\theta)\left\{1_{ls=ni} \cdot 1_{qr=kj} + \mathbf{e'}_{2(n-1)+k}\left[\boldsymbol{\beta}(\mathbf{I}-\boldsymbol{\rho})\frac{\partial \log \mathbf{w}}{\partial h_{ls}^{qr}} + \boldsymbol{\rho}\frac{\partial \log \mathbf{t}}{\partial h_{ls}^{qr}} + \right.\right.$$

$$+\boldsymbol{\gamma}\mathbf{\Pi'}(\mathbf{I}-\boldsymbol{\gamma}\mathbf{\Pi'})^{-1}\left(\boldsymbol{\beta}(\mathbf{I}-\boldsymbol{\rho})\frac{\partial \log \mathbf{w}}{\partial h_{ls}^{qr}} + \boldsymbol{\rho}\frac{\partial \log \mathbf{t}}{\partial h_{ls}^{qr}} + \boldsymbol{\gamma} diag^{-1}(\mathbf{\Pi'}\mathbf{e}_{2(l-1)+q}\mathbf{e'}_{2(s-1)+r})\right)$$

$$\left. +\boldsymbol{\gamma} diag^{-1}(\mathbf{\Pi'}\mathbf{e}_{2(l-1)+q}\mathbf{e'}_{2(s-1)+r})\right] +$$

$$-\mathbf{e}'_{2(i-1)+j}\left[\mathbf{\Pi}'(\mathbf{I}-\boldsymbol{\gamma}\mathbf{\Pi}')^{-\mathbf{1}}\left(\boldsymbol{\beta}(\mathbf{I}-\boldsymbol{\rho})\frac{\partial\log\mathbf{w}}{\partial h_{ls}^{qr}}+\boldsymbol{\rho}\frac{\partial\log\mathbf{t}}{\partial h_{ls}^{qr}}+\boldsymbol{\gamma}diag^{-1}(\mathbf{\Pi}'\mathbf{e}_{2(l-1)+q}\mathbf{e}'_{2(s-1)+r})\right)\right.$$

$$\left.\left.+diag^{-1}(\mathbf{\Pi}'\mathbf{e}_{2(l-1)+q}\mathbf{e}'_{2(s-1)+r})\right]\right\}$$

And using the fact that $\mathbf{I}+\boldsymbol{\gamma}\mathbf{\Pi}'(\mathbf{I}-\boldsymbol{\gamma}\mathbf{\Pi}')^{-1}=(\mathbf{I}-\boldsymbol{\gamma}\mathbf{\Pi}')^{-1}$:

$$=(1-\theta)\left\{1_{ls=ni}\cdot 1_{qr=kj}+\mathbf{e}'_{2(n-1)+k}\left[(\mathbf{I}-\boldsymbol{\gamma}\mathbf{\Pi}')^{-1}\left(\boldsymbol{\beta}(\mathbf{I}-\boldsymbol{\rho})\frac{\partial\log\mathbf{w}}{\partial h_{ls}^{qr}}+\boldsymbol{\rho}\frac{\partial\log\mathbf{t}}{\partial h_{ls}^{qr}}\right)\right]+\right.$$

$$-\mathbf{e}'_{2(i-1)+j}\left[\mathbf{\Pi}'(\mathbf{I}-\boldsymbol{\gamma}\mathbf{\Pi}')^{-\mathbf{1}}\left(\boldsymbol{\beta}(\mathbf{I}-\boldsymbol{\rho})\frac{\partial\log\mathbf{w}}{\partial h_{ls}^{qr}}+\boldsymbol{\rho}\frac{\partial\log\mathbf{t}}{\partial h_{ls}^{qr}}\right)\right]+$$

$$+\mathbf{e}'_{2(n-1)+k}(\mathbf{I}-\boldsymbol{\gamma}\mathbf{\Pi}')^{-1}\boldsymbol{\gamma}diag^{-1}(\mathbf{\Pi}'\mathbf{e}_{2(l-1)+q}\mathbf{e}'_{2(s-1)+r})$$

$$\left.-\mathbf{e}'_{2(i-1)+j}\left[\mathbf{I}+\mathbf{\Pi}'(\mathbf{I}-\boldsymbol{\gamma}\mathbf{\Pi}')^{-1}\boldsymbol{\gamma}\right]diag^{-1}(\mathbf{\Pi}'\mathbf{e}_{2(l-1)+q}\mathbf{e}'_{2(s-1)+r})\right\}=$$

$$=(1-\theta)\left\{1_{ls=ni}\cdot 1_{qr=kj}+\mathbf{e}'_{2(n-1)+k}\left[(\mathbf{I}-\boldsymbol{\gamma}\mathbf{\Pi}')^{-1}\left(\boldsymbol{\beta}(\mathbf{I}-\boldsymbol{\rho})\frac{\partial\log\mathbf{w}}{\partial h_{ls}^{qr}}+\boldsymbol{\rho}\frac{\partial\log\mathbf{t}}{\partial h_{ls}^{qr}}\right)\right]+\right.$$

$$-\mathbf{e}_{2(i-1)+j}\left[\mathbf{\Pi}'(\mathbf{I}-\boldsymbol{\gamma}\mathbf{\Pi}')^{-\mathbf{1}}\left(\boldsymbol{\beta}(\mathbf{I}-\boldsymbol{\rho})\frac{\partial\log\mathbf{w}}{\partial h_{ls}^{qr}}+\boldsymbol{\rho}\frac{\partial\log\mathbf{t}}{\partial h_{ls}^{qr}}\right)\right]+$$

$$\left.+(1-\beta_r^s)(1-\rho_r^s)\psi_{ns}^{kr}\iota_{ls}^{qr}-1_{ls=ni}\cdot 1_{qr=kj}\cdot\iota_{ls}^{qr}-\sum_{m\in\mathcal{N}}\sum_{h\in\mathcal{J}}(1-\beta_r^s)(1-\rho_r^s)\iota_{mi}^{hj}\psi_{ms}^{hr}\iota_{ls}^{qr}\right\} \tag{29}$$

where with ψ_{in}^{jk} we denote the entries of the cost-based Leontief inverse $(\mathbf{I} - \boldsymbol{\gamma}\boldsymbol{\Pi}')^{-1} \in \mathcal{M}(NJ, NJ)$. Moreover, since $\omega_{ni}^{kj} = (1-\beta_i^j)(1-\rho_i^j)\frac{\tilde{\omega}_{ni}^{kj}}{\tilde{\tau}_{ni}^{kj}}$, we have:

$$\frac{\partial \log \omega_{ni}^{kj}}{\partial h_{ls}^{qr}} = \frac{\partial \log \tilde{\omega}_{ni}^{kj}}{\partial h_{ls}^{qr}} - \frac{\partial \log \tilde{\tau}_{ni}^{kj}}{\partial h_{ls}^{qr}} = \frac{\partial \log \tilde{\omega}_{ni}^{kj}}{\partial h_{ls}^{qr}} - 1_{ni=ls} \cdot 1_{kj=qr} \tag{30}$$

In the case in which $\beta_i^j = \beta,\ \rho_i^j = \rho\ \forall i, j$:

$$\frac{\partial \log \tilde{\omega}_{ni}^{kj}}{\partial h_{ls}^{qr}} = (1-\theta)\left\{1_{ls=ni} \cdot 1_{qr=kj} + \mathbf{e}'_{2(n-1)+k}\left[(\mathbf{I} - \gamma\boldsymbol{\Pi}')^{-1}\left(\beta(1-\rho)\frac{\partial \log \mathbf{w}}{\partial h_{ls}^{qr}} + \rho\frac{\partial \log \mathbf{t}}{\partial h_{ls}^{qr}}\right)\right] + \right.$$

$$-\mathbf{e}_{2(i-1)+j}\left[\boldsymbol{\Pi}'(\mathbf{I} - \gamma\boldsymbol{\Pi}')^{\mathbf{-1}}\left(\beta(1-\rho)\frac{\partial \log \mathbf{w}}{\partial h_{ls}^{qr}} + \rho\frac{\partial \log \mathbf{t}}{\partial h_{ls}^{qr}}\right)\right] +$$

$$\left. +(1-\beta)(1-\rho)\psi_{ns}^{kr}\iota_{ls}^{qr} - \psi_{is}^{jr}\iota_{ls}^{qr}\right\}$$

Now, the percentage change of cost shares following the introduction of the marginal increase in trade wedges can be approximated by the following first-order Taylor approximation around the steady-state:

$$d\log \tilde{\omega}_{ni}^{kj} = \sum_{l\in\mathcal{N}}\sum_{s\in\mathcal{N}}\sum_{q\in\mathcal{J}}\sum_{r\in\mathcal{J}} \frac{\partial \log \tilde{\omega}_{ni}^{kj}}{\partial h_{ls}^{qr}} dh_{ls}^{qr} =$$

$$= \sum_{l\in\mathcal{N}}\sum_{s\in\mathcal{N}}\sum_{q\in\mathcal{J}}\sum_{r\in\mathcal{J}} \frac{\partial \log \tilde{\omega}_{ni}^{kj}}{\partial h_{ls}^{qr}} (\rho_l^q + dCBAM_{ls}^{qr})$$

where $\frac{\partial \log \tilde{\omega}_{ni}^{kj}}{\partial h_{ls}^{qr}}$ is given by (28) and $dCBAM_{ls}^{qr}$ by (27). However, for our purposes, we consider the simplified version in which a unique country i introduces the CBAM on a special good k produced in country n and factor shares are uniform across countries and sectors. We can rewrite the above expression as:

$$d\log \tilde{\omega}_{ni}^{kj} = (1-\theta)\left[(\rho + dCBAM_{ni}^{kj}) + (1-\beta)(1-\rho)\sum_{r\in\mathcal{J}}\left(\psi_{ni}^{kr} - \psi_{ii}^{jr}\right)\iota_{ni}^{kr}(\rho + dCBAM_{ni}^{kr})\right] +$$

$$+(1-\theta)\left[\mathbf{e}'_{2(n-1)+k}(1-\gamma\mathbf{\Pi}')^{-1}\left(\beta(1-\rho)\frac{\partial\log\mathbf{w}}{\partial\mathbf{h}}+\rho\frac{\partial\log\mathbf{t}}{\partial\mathbf{h}}\right)+\right.$$

$$\left.-\mathbf{e}'_{2(i-1)+j}(1-\gamma\mathbf{\Pi}')^{-1}\left(\beta(1-\rho)\frac{\partial\log\mathbf{w}}{\partial\mathbf{h}}+\rho\frac{\partial\log\mathbf{t}}{\partial\mathbf{h}}\right)\right](\boldsymbol{\rho}+d\mathbf{CBAM})$$

where $\mathbf{h}=(h_{ni}^{k1},h_{ni}^{k2},...,h_{ni}^{kN})\in\mathbb{R}^{NJ}$ and $\mathbf{CBAM}=(CBAM_{ni}^{k1},CBAM_{ni}^{k2},...,CBAM_{ni}^{kN})\in\mathbb{R}^{NJ}$, with $dCBAM_{ni}^{kj}$ given by (27). All derivatives are evaluated at the steady state, where $\mathbf{h}=\mathbf{0}$.

Proposition A.2. — *(**Gross National Expenditure**) The first-order approximation of the change in real GNE of country i following the introduction of the CBAM, around the steady-state is given by:*

$$d\log W_i=\sum_{l\in\mathcal{N}}\sum_{s\in\mathcal{N}}\sum_{q\in\mathcal{J}}\sum_{r\in\mathcal{J}}\left[\frac{w_i\overline{L}_i}{I_i}\frac{\partial\log w_i}{\partial h_{ls}^{qr}}+\frac{t_iE_i}{I_i}\left(\mathbf{1}_{\mathcal{N}_{c(i)}}\frac{\partial\log t_i}{\partial h_{ls}^{qr}}+\mathbf{1}_{\mathcal{N}_{nc(i)}}\frac{\partial\log E_i}{\partial h_{ls}^{qr}}\right)\right](\rho_l^q+dCBAM_{ls}^{qr})$$

$$-\sum_{l\in\mathcal{N}}\sum_{s\in\mathcal{N}}\sum_{q\in\mathcal{J}}\sum_{r\in\mathcal{J}}(\mathbf{e}_i\otimes\mathbf{1}_J)'\boldsymbol{\chi}\frac{\partial\log\mathbf{p}}{\partial h_{ls}^{qr}}(\rho_l^q+dCBAM_{ls}^{qr})+$$

$$+(1-\beta_i^j)(1-\rho_i^j)\lambda_i^j\sum_{l\in\mathcal{N}}\sum_{q\in\mathcal{J}}\tilde{\omega}_{li}^{qj}(\rho_l^q+dCBAM_{ls}^{qr})\tag{31}$$

where $\mathbf{e}_i\in\mathbb{R}^N$ is th i-th standard basis vector, $\boldsymbol{\chi}=diag^{-1}(\chi_1^1,...,\chi_N^J)'\in\mathcal{M}(NJ\times NJ)$ is the diagonal matrix of consumption shares χ_i^j, that in equilibrium are equal to ν_i^j, $\frac{\partial\log\mathbf{p}}{\partial h_{ls}^{qr}}$ is given by (23) and $dCBAM_{ls}^{qr}$ is given by (27).

Proof. We recall the definition of each country's nominal Gross National Expenditure (GNE) given by $GNE_i=\sum_{j\in\mathcal{J}}p_i^jc_i^j$ and define $\nu_i^j=p_i^jc_i^j/GNE_i$. Thus, taking derivatives with respect to h_{ls}^{qr}, the percentage change in nominal Gross National Expenditure of country i is equal to:

$$\frac{\partial\log GNE_i}{\partial h_{ni}^{kj}}=\underbrace{\sum_{j\in\mathcal{J}}\nu_i^j\frac{\partial\log p_i^j}{\partial h_{ni}^{kj}}}_{\text{price effect}}+\underbrace{\sum_{j\in\mathcal{J}}\nu_i^j\frac{\partial\log c_i^j}{\partial h_{ni}^{kj}}}_{\text{real effect}}\equiv\frac{\partial\log P_i}{\partial h_{ni}^{kj}}+\frac{\partial\log W_i}{\partial h_{ni}^{kj}}\tag{32}$$

where $\frac{\partial\log p_i^j}{\partial h_{ls}^{qr}}$ is equal to the $(2(i-1)+j)th$ element of the vector $\frac{\partial\log\mathbf{p}}{\partial h_{ls}^{qr}}$ in (23).

Given the assumption of locally non-satiated preferences, total expenditure on final goods of country i is equal to the national income I_i, coinciding with:

$$I_i = w_i \overline{L}_i + t_i E_i + \sum_{j \in \mathcal{J}} (1-\beta_i^j)(1-\rho_i^j) p_i^j q_i^j \sum_{n \in \mathcal{N}} \sum_{k \in \mathcal{J}} \left(\tilde{\tau}_{ni}^{kj} - 1\right) \tilde{\omega}_{ni}^{kj} + \overline{D_i}$$

Differentiating and using the fact that $d \log x = dx/x$, we have:

$$\frac{\partial \log I_i}{\partial h_{ls}^{qr}} = \frac{w_i \overline{L}_i}{I_i} \frac{\partial \log w_i}{\partial h_{ls}^{qr}} + \frac{t_i E_i}{I_i} \left(\mathbf{1}_{\mathcal{N}_{c(i)}} \frac{\partial \log t_i}{\partial h_{ls}^{qr}} + \mathbf{1}_{\mathcal{N}_{nc(i)}} \frac{\partial \log E_i}{\partial h_{ls}^{qr}} \right) + \frac{1}{I_i} \frac{\partial R_i}{\partial h_{ls}^{qr}}$$

where $R_i = \sum_{j \in \mathcal{J}} (1-\beta_i^j)(1-\rho_i^j) \lambda_i^j GNE \sum_{n \in \mathcal{N}} \sum_{k \in \mathcal{J}} \left(\tilde{\tau}_{ni}^{kj} - 1\right) \tilde{\omega}_{ni}^{kj}$ and in steady-state:

$$\frac{\partial R_i}{\partial h_{ls}^{qr}} = \sum_{j \in \mathcal{J}} (1-\beta_i^j)(1-\rho_i^j) \lambda_i^j \sum_{n \in \mathcal{N}} \sum_{k \in \mathcal{J}} \frac{\partial \log \tilde{\tau}_{ni}^{kj}}{\partial h_{ls}^{qr}} \tilde{\omega}_{ni}^{kj} =$$

$$= 1_{ls=ni} \cdot 1_{qr=kj} \cdot \sum_{j \in \mathcal{J}} (1-\beta_i^j)(1-\rho_i^j) \lambda_i^j \tilde{\omega}_{ni}^{kj}$$

Since, in equilibrium, $GNE_i = I_i$ the percentage change in nominal Gross National Expenditure of county i is given by:

$$\frac{\partial \log GNE_i}{\partial h_{ls}^{qr}} = \left[\frac{w_i \overline{L}_i}{I_i} \frac{\partial \log w_i}{\partial h_{ls}^{qr}} + \frac{t_i E_i}{I_i} \left(\mathbf{1}_{\mathcal{N}_{c(i)}} \frac{\partial \log t_i}{\partial h_{ls}^{qr}} + \mathbf{1}_{\mathcal{N}_{nc(i)}} \frac{\partial \log E_i}{\partial h_{ls}^{qr}} \right) + \right.$$

$$\left. + 1_{ls=ni} \cdot 1_{qr=kj} \cdot \sum_{j \in \mathcal{J}} (1-\beta_i^j)(1-\rho_i^j) \lambda_i^j \tilde{\omega}_{ni}^{kj} \right] \tag{33}$$

And the corresponding change in real GNE, reflecting changes in welfare, is given by:

$$\frac{\partial \log W_i}{\partial h_{ls}^{qr}} = \frac{\partial \log GNE_i}{\partial h_{ls}^{qr}} - \frac{\partial \log P_i}{\partial h_{ls}^{qr}} =$$

$$= \left[\frac{w_i \overline{L}_i}{I_i} \frac{\partial \log w_i}{\partial h_{ls}^{qr}} + \frac{t_i E_i}{I_i} \left(\mathbf{1}_{\mathcal{N}_{c(i)}} \frac{\partial \log t_i}{\partial h_{ls}^{qr}} + \mathbf{1}_{\mathcal{N}_{nc(i)}} \frac{\partial \log E_i}{\partial h_{ls}^{qr}} \right) + \right.$$

$$\left. + 1_{ls=ni} \cdot 1_{qr=kj} \cdot \sum_{r \in \mathcal{J}} (1 - \beta_s^r)(1 - \rho_s^r) \lambda_s^r \tilde{\omega}_{ls}^{qr} \right] +$$

$$-(\mathbf{e}_i \otimes \mathbf{1}_J)' \boldsymbol{\chi} \frac{\partial \log \mathbf{p}}{\partial h_{ls}^{qr}} \tag{34}$$

where $\mathbf{e}_i \in \mathbb{R}^N$ is th i-th standard basis vector, $\boldsymbol{\chi} = diag^{-1}(\chi_1^1, ..., \chi_N^J)' \in \mathcal{M}(NJ \times NJ)$ is the diagonal matrix of consumption shares χ_i^j, that in equilibrium are equal to ν_i^j and $\frac{\partial \log \mathbf{p}}{\partial h_{ls}^{qr}}$ is given by (23).

Finally, the first-order approximations of the percentage change in real Gross National Expenditure following the marginal increase in trade wedges is given by:

$$d \log W_i = \sum_{l \in \mathcal{N}} \sum_{s \in \mathcal{N}} \sum_{q \in \mathcal{J}} \sum_{r \in \mathcal{J}} \frac{\partial \log W_i}{\partial h_{ls}^{qr}} dh_{ls}^{qr} =$$

$$\sum_{l \in \mathcal{N}} \sum_{s \in \mathcal{N}} \sum_{q \in \mathcal{J}} \sum_{r \in \mathcal{J}} \frac{\partial \log W_i}{\partial h_{ls}^{qr}} (\rho_l^q + dCBAM_{ls}^{qr})$$

where $dCBAM_{ls}^{qr}$ is given by (27) and $\frac{\partial \log W_i}{\partial h_{ls}^{qr}}$ by (34). In order to gain a better insight into the mechanisms driving the change, we consider the special case in which a unique country i introduces the CBAM on a specific good k produced in country n and we set factor shares equal across countries and sectors. The above expression can be rewritten as:

$$d \log W_i = d \log GNE_i - (\mathbf{e}_i \otimes \mathbf{1}_J)' \boldsymbol{\chi} \frac{\partial \log \mathbf{p}}{\partial \mathbf{h}} (\boldsymbol{\rho} + d\mathbf{CBAM})$$

which, in turn, becomes:

$$d \log W_i = \left[\frac{w_i \overline{L}_i}{I_i} \frac{\partial \log w_i}{\partial \mathbf{h}} + \frac{t_i E_i}{I_i} \left(\mathbf{1}_{\mathcal{N}_{c(i)}} \frac{\partial \log t_i}{\partial \mathbf{h}} + \mathbf{1}_{\mathcal{N}_{nc(i)}} \frac{\partial \log E_i}{\partial \mathbf{h}} \right) \right] (\boldsymbol{\rho} + d\mathbf{CBAM}) +$$

$$-(\mathbf{e}_i \otimes \mathbf{1}_J)' \boldsymbol{\chi} \frac{\partial \log \mathbf{p}}{\partial \mathbf{h}} (\boldsymbol{\rho} + d\mathbf{CBAM}) +$$

$$+(1-\beta)(1-\rho)\sum_{j\in\mathcal{J}}\lambda_i^j\sum_{r\in\mathcal{J}}\iota_{ni}^{kr}(\rho+dCBAM_{ni}^{kr}) \tag{35}$$

where, given our model assumptions, in equilibrium $\nu_i^j = \chi_i^j$ and $\boldsymbol{\chi} = diag(\chi_1^1, ..., \chi_N^J) \in \mathcal{M}(NJ \times NJ)$. $\frac{\partial \log \mathbf{p}}{\partial \mathbf{h}}$ is given by (23), $\mathbf{h} = (h_{ni}^{k1}, h_{ni}^{k2}, ..., h_{ni}^{kN}) \in \mathbb{R}^{NJ}$ and $\mathbf{CBAM} = (CBAM_{ni}^{k1}, CBAM_{ni}^{k2}, ..., CBAM_{ni}^{kN}) \in \mathbb{R}^{NJ}$, with $dCBAM_{ni}^{kj}$ given by (27). All derivatives are evaluated at the steady state, where $\mathbf{h} = \mathbf{0}$.

Proposition A.3. — ***Effect on shocks on emissions embodied in imports*** *The first-order approximation around the steady-state of the change in emissions embodied in direct and indirect European imports following the introduction of the CBAM is given by:*

$$d\log EEI(EU) = \sum_{l\in\mathcal{N}}\sum_{s\in\mathcal{N}}\sum_{q\in\mathcal{J}}\sum_{r\in\mathcal{J}}\frac{\partial \log EEI(EU)}{\partial h_{ls}^{qr}}(\rho_l^q + dCBAM_{ls}^{qr}) =$$

$$= \sum_{l\in\mathcal{N}}\sum_{s\in\mathcal{N}}\sum_{q\in\mathcal{J}}\sum_{r\in\mathcal{J}}\Bigg\{\Bigg[\frac{\partial \log diag(\mathbf{e})}{\partial h_{ls}^{qr}} + \tilde{\boldsymbol{\rho}}(\mathbf{I}-\gamma\boldsymbol{\Pi}')^{-1}\boldsymbol{\gamma}\frac{\partial\tilde{\boldsymbol{\Omega}}}{\partial h_{ls}^{qr}}\boldsymbol{\rho}^{-1} +$$

$$+\tilde{\boldsymbol{\rho}}(\mathbf{I}-\boldsymbol{\gamma}\boldsymbol{\Pi}')^{-1}\boldsymbol{\gamma}\frac{\partial\tilde{\boldsymbol{\Omega}}_{\mathbf{EU}}}{\partial h_{ls}^{qr}}diag(\boldsymbol{\Lambda})\mathbf{EEI}(EU)^{-1}\Bigg]\mathbf{v}\mathbf{1}'\Bigg\}(\rho_l^q + dCBAM_{ls}^{qr})$$

where $dCBAM_{ls}^{qr}$ is given by (6) and $\frac{\partial \log \tilde{\omega}_{nm}^{kh}}{\partial h_{ls}^{qr}}$ by (29).

Proof. Emissions embodied in trade are calculated using the vector of production-based emissions and input-output multipliers. We borrow the definition from the OECD (Yamano and Guilhoto, 2020) and we adapt it to align with the structure of our model. The emissions embodied in imports are given by the following vector $\mathbf{EEI} \in \mathbb{R}^{NJ}$ with entries corresponding to the emissions generated from the production of each good $j \in \mathcal{J}$ in every country $i \in \mathcal{N}$ embodied in imports from all trade partners. In particular, the first equivalence in equation (17) corresponds to the OECD definition, while the subsequent equalities restates it in terms of our notation and modeling framework:

$$\mathbf{EEI} \equiv \tilde{\boldsymbol{\rho}}(\mathbf{I}-\boldsymbol{\Omega})^{-1}\mathbf{X}\mathbf{1} = \left[\tilde{\boldsymbol{\rho}}(\mathbf{I}-\boldsymbol{\Omega})^{-1}\gamma\tilde{\boldsymbol{\Omega}}diag(\boldsymbol{\Lambda})\mathbf{1}\right]GNE$$

where $\tilde{\boldsymbol{\rho}} = diag(\tilde{\rho}_1^1, ..., \tilde{\rho}_N^J) \in \mathcal{M}(NJ \times NJ)$ is a diagonal matrix with entries $\tilde{\rho}_i^j = e_i^j/p_i^j q_i^j \ \forall i \in \mathcal{N}, j \in \mathcal{J}$, $\mathbf{X} \in \mathbb{M}(NJ \times NJ)$ is the matrix of trade flows and we use the fact that each element $p_{ni}^{kj} z_{ni}^{kj} \in \mathbf{X}$ can be rewritten as $p_{ni}^{kj} z_{ni}^{kj} = \gamma_i^j \tilde{\omega}_{ni}^{kj} \lambda_i^j GNE$. Given our interest in the emissions embodied in all intermediate goods imported by European producers, we first consider the change in production-related emissions of each country-sector pair embedded in the goods exported to the EU-ETS and then aggregate them across all exporting countries. First, denote by $\tilde{\boldsymbol{\Omega}}_{EU}$ the matrix of input-output coefficients, with non-zero entries only for European destination sectors, excluding intra-EU trade. Then:

$$\mathbf{EEI}(\text{EU}) = \left[\tilde{\boldsymbol{\rho}}(\mathbf{I}-\boldsymbol{\Omega})^{-1}\boldsymbol{\gamma}\tilde{\boldsymbol{\Omega}}_{EU}diag(\boldsymbol{\Lambda})\mathbf{1}\right]GNE$$

And, taking derivatives and evaluating them at the steady-state, we have that the change in embodied emissions in goods imported by the European producers is given by:

$$\frac{\partial \mathbf{EEI}(\text{EU})}{\partial h_{ls}^{qr}} = \frac{\partial \tilde{\boldsymbol{\rho}}}{\partial h_{ls}^{qr}}\tilde{\boldsymbol{\rho}}^{-1}\tilde{\boldsymbol{\rho}}(\mathbf{I}-\boldsymbol{\gamma}\boldsymbol{\Pi}')^{-1}\gamma\boldsymbol{\Pi}'_{EU}diag(\boldsymbol{\Lambda})\mathbf{1}+$$

$$+\tilde{\boldsymbol{\rho}}(\mathbf{I}-\boldsymbol{\gamma}\boldsymbol{\Pi}')^{-1}\frac{\partial(\mathbf{I}-\boldsymbol{\Omega})}{\partial h_{ls}^{qr}}(\mathbf{I}-\boldsymbol{\gamma}\boldsymbol{\Pi}')^{-1}\boldsymbol{\gamma}\boldsymbol{\Pi}'_{EU}diag(\boldsymbol{\Lambda})\mathbf{1}+$$

$$+\tilde{\boldsymbol{\rho}}(\mathbf{I}-\boldsymbol{\gamma}\boldsymbol{\Pi}')^{-1}\boldsymbol{\gamma}\frac{\partial\tilde{\boldsymbol{\Omega}}_{\mathbf{EU}}}{\partial h_{ls}^{qr}}diag(\boldsymbol{\Lambda})\mathbf{1}+\tilde{\boldsymbol{\rho}}(\mathbf{I}-\boldsymbol{\gamma}\boldsymbol{\Pi}')^{-1}\boldsymbol{\gamma}\tilde{\boldsymbol{\Omega}}_{\mathbf{EU}}\frac{\partial diag(\boldsymbol{\Lambda})}{\partial h_{ls}^{qr}}\mathbf{1}$$

where we use the fact that world GNE is normalised to 1. Readjusting terms:

$$\frac{\partial \log \mathbf{EEI}(\text{EU})}{\partial h_{ls}^{qr}} = \frac{\partial \log \tilde{\boldsymbol{\rho}}}{\partial h_{ls}^{qr}} + \frac{\log diag(\boldsymbol{\Lambda})}{\partial h_{ls}^{qr}} + \tilde{\boldsymbol{\rho}}(\mathbf{I}-\boldsymbol{\gamma}\boldsymbol{\Pi}')^{-1}\boldsymbol{\gamma}\frac{\partial\tilde{\boldsymbol{\Omega}}}{\partial h_{ls}^{qr}}\tilde{\boldsymbol{\rho}}^{-1}+$$

$$+\tilde{\boldsymbol{\rho}}(\mathbf{I}-\boldsymbol{\gamma}\boldsymbol{\Pi}')^{-1}\boldsymbol{\gamma}\frac{\partial\tilde{\boldsymbol{\Omega}}_{\mathbf{EU}}}{\partial h_{ls}^{qr}}diag(\boldsymbol{\Lambda})\mathbf{EEI}(\text{EU})^{-1}$$

Recalling that $\tilde{\rho}_i^j = e_i^j/(p_i^j q_i^j) = e_i^j/(\lambda_i^j GNE)$, we have $\log \tilde{\rho}_i^j = log e_i^j - \log \lambda_i^j$ and thus, for each country-sector pair we have:

$$\frac{\partial \log EEI_i^j(\text{EU})}{\partial h_{ls}^{qr}} = \frac{\partial \log e_i^j}{\partial h_{ls}^{qr}} + \tilde{\rho}_i^j \sum_{n\in\mathcal{N}} \sum_{k\in\mathcal{J}} \psi_{in}^{jk} \sum_{m\in\mathcal{N}} \sum_{h\in\mathcal{J}} \frac{1}{\tilde{\rho}_m^h} \omega_{nm}^{kh} \frac{\partial \log \tilde{\omega}_{nm}^{kh}}{\partial h_{ls}^{qr}} +$$

$$+ \frac{1}{EEI_i^j(\text{EU})} \tilde{\rho}_i^j \sum_{n\in\mathcal{N}\setminus\{\text{EU}\}} \sum_{k\in\mathcal{J}} \psi_{in}^{jk} \sum_{h\in\mathcal{J}} \omega_{n\text{EU}}^{kh} \frac{\partial \log \tilde{\omega}_{n\text{EU}}^{kh}}{\partial h_{ls}^{qr}} \lambda_{\text{EU}}^h \tag{36}$$

Finally, define $\mathbf{v}$ as the vector with the first J entries equal to 0, while the rest being equal to the corresponding country-sectoral embodied emissions $EEI_i^j(\text{EU})$ as a share of total emissions embodied in European imports. Aggregating across exporting countries, the change in emissions embodied in goods imported by European producers following the marginal increase in trade wedges h_{ls}^{qr} is given by:

$$\frac{\partial \log EEI(\text{EU})}{\partial h_{ls}^{qr}} = \sum_{i\in N\setminus\{\text{EU}\}} \sum_{j\in\mathcal{J}} \frac{EEI_i^j(\text{EU})}{EEI(EU)} \frac{\partial \log EEI_i^j(\text{EU})}{\partial h_{ls}^{qr}} = \frac{\partial \log \mathbf{EEI}(\text{EU})}{\partial h_{ls}^{qr}} \mathbf{v1}'$$

And to a first-order approximation, the change in emissions embodied in direct and indirect European imports is given by:

$$d \log EEI(\text{EU}) = \sum_{l\in\mathcal{N}} \sum_{s\in\mathcal{N}} \sum_{q\in\mathcal{J}} \sum_{r\in\mathcal{J}} \frac{\partial \log EEI(\text{EU})}{\partial h_{ls}^{qr}} (\rho_l^q + dCBAM_{ls}^{qr}) =$$

$$= \sum_{l\in\mathcal{N}} \sum_{s\in\mathcal{N}} \sum_{q\in\mathcal{J}} \sum_{r\in\mathcal{J}} \left\{ \left[\frac{\partial \log diag(\mathbf{e})}{\partial h_{ls}^{qr}} + \tilde{\boldsymbol{\rho}}(\mathbf{I} - \gamma\mathbf{\Pi}')^{-1} \boldsymbol{\gamma} \frac{\partial \tilde{\mathbf{\Omega}}}{\partial h_{ls}^{qr}} \boldsymbol{\rho}^{-1} + \right.\right.$$

$$\left.\left. + \tilde{\boldsymbol{\rho}}(\mathbf{I} - \boldsymbol{\gamma}\mathbf{\Pi}')^{-1} \boldsymbol{\gamma} \frac{\partial \tilde{\mathbf{\Omega}}_{\mathbf{EU}}}{\partial h_{ls}^{qr}} diag(\mathbf{\Lambda}) \mathbf{EEI}(\text{EU})^{-1} \right] \mathbf{v1}' \right\} (\rho_l^q + dCBAM_{ls}^{qr})$$

where $dCBAM_{ls}^{qr}$ is given by (6) and $\frac{\partial \log \tilde{\omega}_{nm}^{kh}}{\partial h_{ls}^{qr}}$ by (29).

In the special case in which a unique country i introduces the CBAM on a specific good k produced in country n and factor shares are equal across countries and sectors, the above expression simplifies in:

$$d \log EEI(\text{EU}) = \left[\frac{\partial \log diag(\mathbf{e})}{\partial \mathbf{h}} + \tilde{\boldsymbol{\rho}}(\mathbf{I} - \gamma \boldsymbol{\Pi}')^{-1} \gamma \frac{\partial \tilde{\boldsymbol{\Omega}}}{\partial \mathbf{h}} \tilde{\boldsymbol{\rho}}^{-1} + \right.$$

$$\left. + \tilde{\boldsymbol{\rho}}(\mathbf{I} - \boldsymbol{\gamma} \boldsymbol{\Pi}')^{-1} \boldsymbol{\gamma} \frac{\partial \tilde{\boldsymbol{\Omega}}_{\mathbf{EU}}}{\partial \mathbf{h}} diag(\boldsymbol{\Lambda}) \mathbf{EEI}(\text{EU})^{-1} \right] \mathbf{v}(\rho + d\mathbf{CBAM})$$

where we can distinguish the effect driven by the change in the emissions used in production (*technology effect*) and by the change in sourcing patterns (*reallocation effect*). Specifically:

$$d \log EEI(\text{EU}) = \underbrace{\frac{\partial \log diag(\mathbf{e})}{\partial \mathbf{h}} \mathbf{v}(\rho + d\mathbf{CBAM})}_{\textit{technology effect}} +$$

$$+ \underbrace{\left[\tilde{\boldsymbol{\rho}}(\mathbf{I} - \gamma \boldsymbol{\Pi}')^{-1} \gamma \frac{\partial \tilde{\boldsymbol{\Omega}}}{\partial \mathbf{h}} \tilde{\boldsymbol{\rho}}^{-1} + \tilde{\boldsymbol{\rho}}(\mathbf{I} - \boldsymbol{\gamma} \boldsymbol{\Pi}')^{-1} \boldsymbol{\gamma} \frac{\partial \tilde{\boldsymbol{\Omega}}_{\mathbf{EU}}}{\partial \mathbf{h}} diag(\boldsymbol{\Lambda}) \mathbf{EEI}(\text{EU})^{-1} \right] \mathbf{v}(\rho + d\mathbf{CBAM})}_{\textit{reallocation effect}}$$

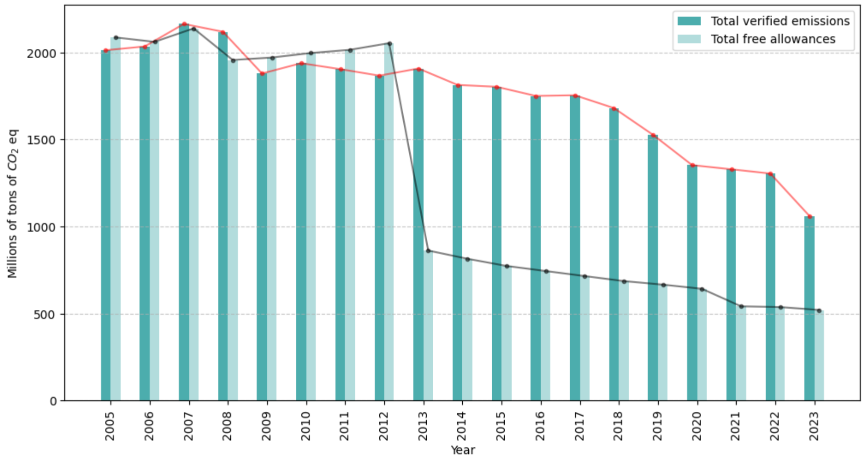

Figure A1: Emissions and Free allowances in the EU ETS (2005-2023)
Source: European Union Transaction Log

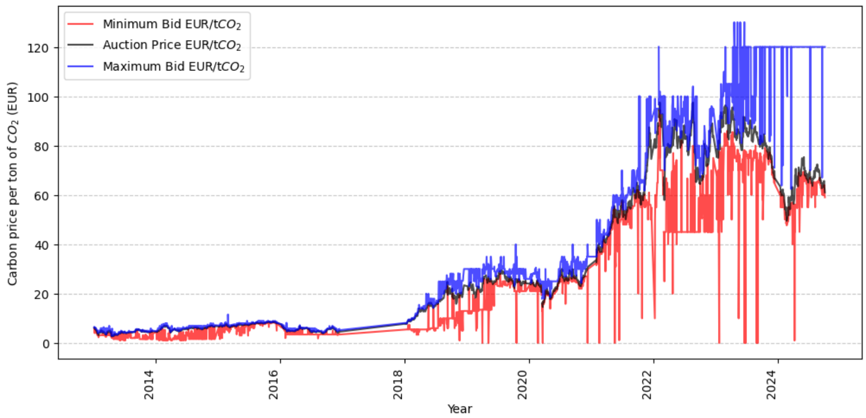

Figure A2: Emissions Allowances Prices (2013-2024)
Source: European Energy Exchange

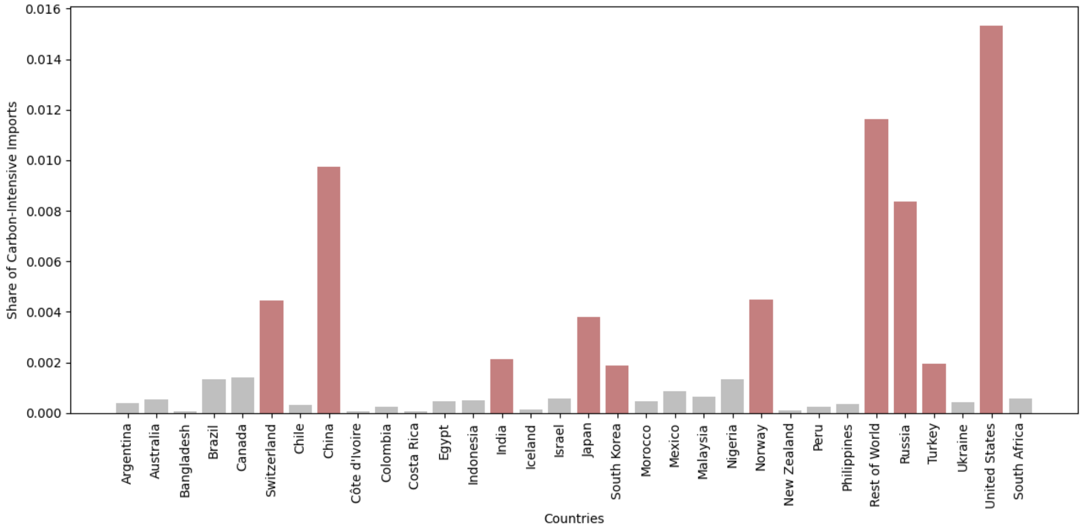

Figure A3: 2018 Share of EU Carbon Intensive Imports by country in Total Intermediate Purchases. Highlighted, the 10 biggest exporters of carbon intensive goods to the EU (in the model, it corresponds to $\tilde{\omega}_{in}^{jk}$ with $n = EU, j \in ETS - sectors$)

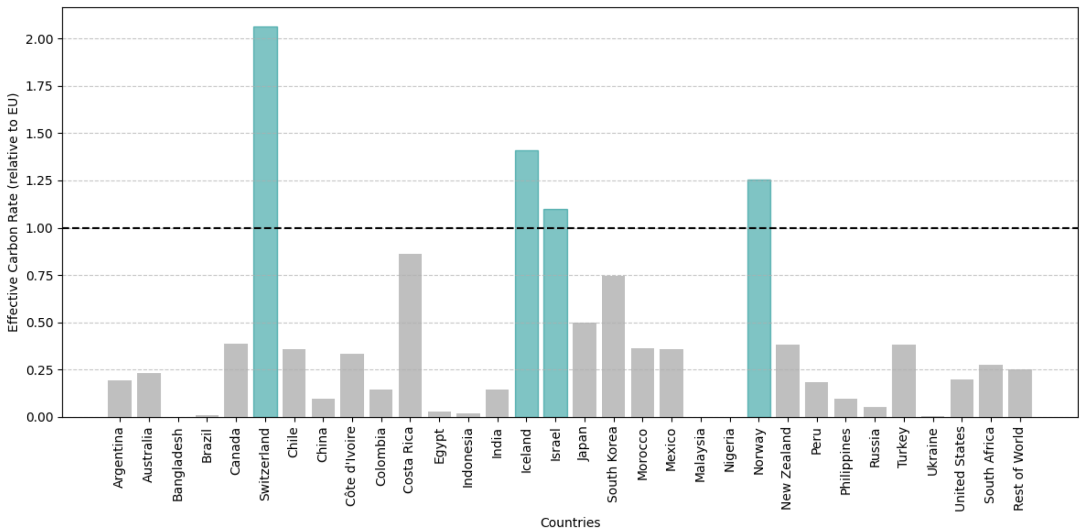

Figure A4: 2018 Effective Carbon Rates (ECR) by country relative to the European ECR. Highlighted the countries whose ECR is greater than the EU one.

A.4 Additional Tables

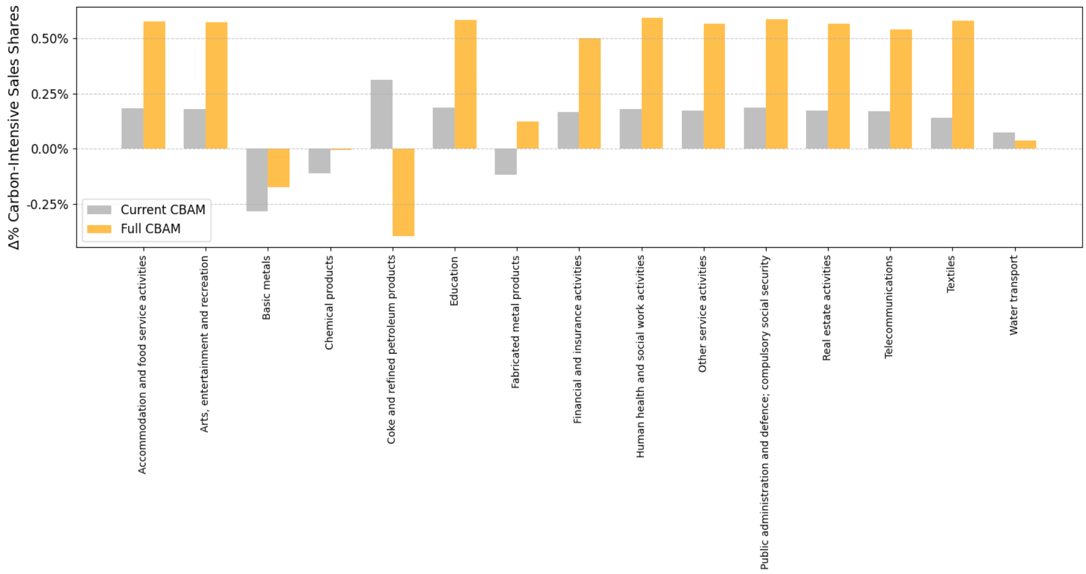

Figure A5: Policy-induced changes in European Sales Shares of selected sectoral goods (% of baseline level) – $\theta = 2$

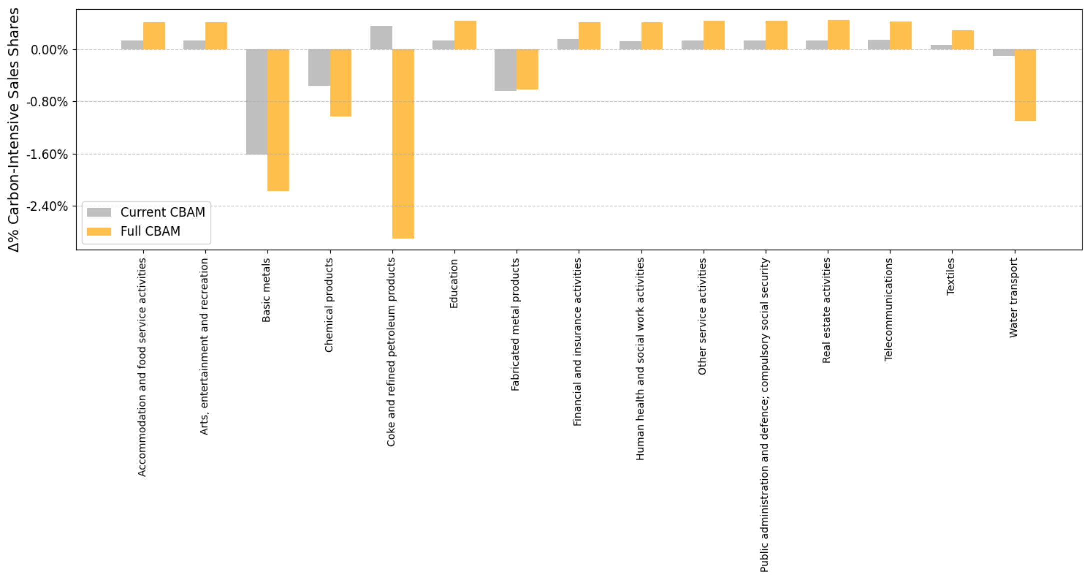

Figure A6: Policy-induced changes in European Sales Shares of selected sectoral goods (% of baseline level) – $\theta = 8$

Country	Mean	Median	Std	Min	Max
European Union	0.0082	0.0006	0.0137	0.0001	0.0511
Argentina	0.002	0.0005	0.0056	1.98e-05	0.0275
Australia	0.0042	0.0005	0.0101	5.06e-05	0.0506
Bangladesh	4.50e-08	5.89e-09	1.60e-07	3.29e-10	8.23e-07
Brazil	0.0001	3.21e-05	0.0003	9.29e-07	0.0011
Canada	0.0084	0.0021	0.0127	0.0002	0.0616
Switzerland	0.0048	0.0013	0.0120	0.0002	0.0616
Chile	0.0074	0.0017	0.0151	0.0001	0.0660
China	0.0024	0.0004	0.0065	4.00e-05	0.0331
Côte d'Ivoire	0.0047	0.0011	0.0113	4.96e-05	0.0460
Colombia	0.0018	0.0004	0.0029	9.80e-06	0.0120
Costa Rica	0.0050	0.0031	0.0068	9.23e-05	0.031
Egypt	0.0010	0.0002	0.0025	1.60e-06	0.0120
Indonesia	0.0006	0.0001	0.0014	5.52e-06	0.0066
India	0.0063	0.0009	0.0175	0.0001	0.0882
Iceland	0.0086	0.0017	0.0180	6.63e-05	0.0791
Israel	0.0171	0.0011	0.0657	7.74e-05	0.3353
Japan	0.0078	0.0006	0.0183	2.19e-05	0.0839
South Korea	0.0163	0.0012	0.0395	0.0003	0.1505
Morocco	0.0384	0.0022	0.1445	3.27e-05	0.7351
Mexico	0.0068	0.0010	0.0214	6.96e-05	0.1096
Malaysia	4.40e-08	7.34e-09	1.37e-07	4.08e-10	7.00e-07
Nigeria	4.04e-08	2.73e-09	8.00e-08	4.85e-11	3.47e-07
Norway	0.0062	0.0007	0.0117	3.06e-07	0.0400
New Zealand	0.0030	0.0004	0.0052	3.37e-06	0.0162
Peru	0.0022	0.0005	0.0049	2.90-05	0.0192
Philippines	0.0023	0.0002	0.0062	1.55e-05	0.0316
Russia	0.0022	0.0004	0.0047	3.20e-05	0.0222
Turkey	0.0081	0.0010	0.0210	3.61e-05	0.0910
Ukraine	0.0002	2.22e-05	0.0003	3.67e-06	0.0013
United States	0.0036	0.0009	0.0097	4.65e-05	0.050
South Africa	0.0171	0.0015	0.0457	0.0001	0.2310
Rest of the World	0.0042	0.0014	0.0090	0.0001	0.0436

Table A2: Descriptive statistics by country of carbon intensities (ρ_i^j) in carbon-intensive sectors.

Variable	Current CBAM		Full CBAM	
	$\theta = 2$	$\theta = 8$	$\theta = 2$	$\theta = 8$
Panel (a) Average Δ% in EU Share of Foreign Purchases				
Total	-0.20 (0.48)	-1.25 (2.48)	-0.37 (0.85)	-2.88 (5.99)
... *of clean intermediate goods*	0.23 (0.14)	1.06 (0.61)	0.82 (0.81)	3.67 (0.61)
... *of dirty intermediate goods*	-0.37 (0.89)	-2.17 (4.48)	-0.70 (1.19)	-4.66 (7.44)
Panel (b) Average Δ% in EU Share of Domestic Purchases				
Total	0.01	0.09	0.02	0.24
... *of clean intermediate goods*	0.03	0.15	0.07	0.38
... *of dirty intermediate goods*	0	0.07	0.01	0.20
Panel (c) Average Δ% in EU Domar Weights				
Total	0.09 (0.11)	-0.05 (0.34)	0.34 (0.22)	-0.06 (0.71)
... *of clean intermediate goods*	0.14 (0.06)	0.08 (0.14)	0.45 (0.18)	0.15 (0.47)
... *of dirty intermediate goods*	0.06 (0.12)	-0.12 (0.39)	0.27 (0.22)	-0.18 (0.80)

Table A3: Policy-induced changes in EU-ETS shares (% of baseline) for $\theta = 2$ and $\theta = 8$. Values are country means; standard deviations in parentheses where applicable.

Variable	**Current CBAM**		**Full CBAM**	
	$\theta = 2$	$\theta = 8$	$\theta = 2$	$\theta = 8$
Panel (a) $\Delta\%$ tons emissions embodied in direct imports				
Total	-1.49	-9.03	-2.41	-18.66
... of clean intermediate goods	0.53	1.38	1.47	4.42
... of dirty intermediate goods	-2.26	-12.92	-3.89	-27.26
Panel (b) $\Delta\%$ tons emissions embodied in direct and indirect imports				
Total	-0.84	-5.89	-1.14	-11.54
... of clean intermediate goods	0.54	1.46	1.51	4.58
... of dirty intermediate goods	-1.20	-7.75	-1.82	-15.61
Panel (c) $\Delta\%$ Emissions Leakage				
Total	-0.04	-0.16	-0.13	-0.29

Table A4: Policy-induced changes in Emissions Embodied in Imports (% of baseline level) for $\theta = 2$ and $\theta = 8$. Values are country means; standard deviations in parentheses where applicable.