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EU's carbon border adjustment mechanism CBAM – Industrial effects

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Abstract

We examine the industrial effects of two measures aimed at mitigating carbon leakage: the EU's scheduled Carbon Border Adjustment Mechanism (CBAM) and the allocation of free emission allowances. Currently, the EU allocates free emission allowances based on output (known as output-based allocation, or OBA) to emission-intensive and trade-exposed (EITE) sectors. This system is slated to be replaced by the CBAM, which imposes a tariff on imports of EITE goods and electricity into the EU. We analyze the effects of this transition, focusing on EU EITE industries. OBA boosts output in the EU's EITE sectors compared to a scenario without any anti-leakage policies. CBAM produces similar effects, except in the case of non-ferrous metals, where output declines. Beyond non-ferrous metals, the positive output effects of CBAM are modest for refined petroleum products and chemical products compared to OBA. Key factors influencing these differences include the sectors' initial emission intensities, export shares, and reliance on intermediate inputs. These factors may also explain why some sectors are resisting the shift from OBA to CBAM.

Keywords: Carbon leakage, carbon border adjustment mechanism, output-based allocation

JEL classification: D61, F18, H23, Q54

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Sammendrag

Vi undersøker effekter på industrisektorer av to tiltak rettet mot karbonlekkasje: EUs planlagte karbontoll (CBAM) og tildeling av gratis utslippskvoter. Inntil nå har EU tildelt gratis utslippskvoter til utslippsintensive og konkurranseutsatte sektorer (EITE) proporsjonalt med produksjonsvolum (OBA). Dette systemet er planlagt erstattet av CBAM, som pålegger en toll på import av EITE-varer og elektrisitet til EU.

Vi analyserer effektene av denne overgangen med søkelys på EUs EITE-industrier. OBA øker produksjonen i EUs EITE-sektorer sammenlignet med et scenario uten anti-lekkasjetiltak. CBAM gir lignende effekter, bortsett fra for ikke-jernholdige metaller som f.eks. aluminium, hvor produksjonen reduseres. De positive effektene CBAM har på produksjon er også beskjedne for raffinerte petroleumsprodukter og kjemiske produkter sammenlignet med OBA. Viktige faktorer som påvirker disse forskjellene inkluderer sektorenes utslippsintensiteter, eksportandeler og bruk av innsatsfaktorer. Disse faktorene kan muligens forklare hvorfor noen sektorer motsetter seg overgangen fra OBA til CBAM.

1. Introduction

In the wake of the Paris agreement (2015) on stabilising global warming well below 2 degrees by the end of this century, the number of countries actively addressing climate change and introducing carbon policies steadily increase. This is materialised in the updated Nationally Determined Contributions (NDCs) to the Paris agreement (NDC, 2022). The European Union (EU) has been a frontrunner in introducing and enforcing ambitious climate policies, and its policies have been a success in reducing carbon emissions. EU’s climate policies have been tightened in the EU Fit for 55 policy (EU, 2022), which is also part of EUs updated NDC to the Paris agreement (NDC, 2022). Despite the updated NDCs, where more than 169 countries have committed to the agreement, there are still large regional differences in emission regulations and carbon prices across the world. Hence there is a risk of carbon leakage, i.e. that emissions outside the EU may increase because of the EU's climate policy, e.g., because emission-intensive and trade-exposed industries (EITE) relocate their production abroad.

The EITE industries, which are all part of the EU Emission trading system (ETS), currently receives a large number of free emission allowances to mitigate carbon leakage. The allocation is proportional to output, so-called output-based allocation (OBA), so that the firms receive more valuable free emission allowances the more they produce. This free allocation will be gradually phased out from 2026 to 2034, in parallel to the phase in of the EU Carbon Border Adjustment Mechanism (CBAM) for third country imports (European Commission, 2023).[1] The CBAM implements a carbon tariff on imports at the border as a part of EU’s Fit for 55 policy to curb carbon leakage (European Commission, 2021a,b).

Two key motivating factors for dealing with carbon leakage are: (*i*) leakage reduces the effectiveness of the domestic climate policy, because domestic emission reductions are offset by increases in foreign emissions; and (*ii*) the negative effects climate policy has on activity, employment and profits in emission intensive industries within the climate coalition. The latter is the focus of this paper. The leakage policies contribute to levelling the playing fields of EU ETS between producers within and outside the coalition. Specifically, we investigate how the EU ETS affects different emission intensive industries (steel, cement, chemical products, etc.) in the EU, and how adverse effects on activity may be ameliorated by the current scheme with free emission allowances versus the upcoming CBAM. Dealing with the effects climate policy has on employment and profits in

[1] The transitional CBAM data collection phase started 1. Oct. 2023. It involves reporting, but no charges, for the sectors iron and steel, cement, aluminum, fertilizers and hydrogen.

emission intensive industries are arguably of key importance for implementation and political acceptance of ambitious climate policies. The EITE industries in EU make up a considerable share of the economy; 12.4 percent of total EU output (GDP) and 7.5 percent of total labour. The international security situation also motivates having producers of important materials and goods such as those produced by the EITE industries within the EU itself (see e.g. European Commission, 2024).[2]

Most studies have shown that border carbon adjustments (BCA) combining a carbon tariff on imports and refunds on export of EITE goods would outperform OBA (Böhringer et al., 2012; 2017a; Fischer and Fox, 2012; Monjon and Quirion, 2011). The export rebate, however, may not be politically feasible, as experts do not agree on whether it is compatible with WTO rules (Ismer and Haussner, 2016; Horn and Mavroidis, 2011; Tamiotti, 2011). Moreover, the feasibility of the CBAM can be reduced with the current legal and practical implementation constraints (Böhringer et al., 2022).[3] The current plan for introduction of CBAM in EU does not include an export rebate, only carbon tariffs on the imports.

With OBA the EITE firms receive the free emission allowances regardless of where the product is sold. Hence, OBA levels the playing field between domestic and foreign firms in both foreign and domestic markets (Böhringer et al., 2017b; Kaushal and Rosendahl, 2020). This contrasts with EU's version of the CBAM, which only levels the playing field in the domestic EU coalition market. Another key difference between the CBAM and the current system with OBA is that electricity production is included in the suggested CBAM, even if it is not considered as a particularly trade-exposed industry. However, indirect emissions are probably going to be part of the EU CBAM and electricity is a major input factor in the production of EITE goods.[4]

In this paper, we compare the effects of the scheduled CBAM with the currently implemented OBA. We focus on the numerical effects at the industry level, and particularly the EITE industries covered by the CBAM. We use a numerical, disaggregated, global CGE-model to analyse the carbon and anti-

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[2] For example, on November 17, 2018, 290 000 demonstrators known as the "Yellow Vests" from around France began what would be the first of many protests against French President Emmanuel Macron's carbon tax hike (https://hir.harvard.edu/frances-yellow-vest-movement-and-the-global-debate-on-climate-change/).

[3] Böhringer et al. (2017b, 2021) and Kaushal and Rosendahl (2020) shows that a certain combination of OBA and a consumption tax would be equivalent to a carbon border adjustment. Further, whereas BCA may be politically contentious to introduce under current WTO rules, a consumption tax does not face the same challenge as it treats domestic and foreign goods symmetrically (Böhringer et al., 2017b; 2021).

[4] Indirect emissions are planned to be part of the EU CBAM (European Commission, 2023).

leakage policies. In contrast to other studies (European Commission, 2021; Böhringer et al., 2015; Aguiar et al., 2022; Korpar et al.,2023), our simulation for the year 2030 includes current climate policies as given by the Nationally Determined Contributions (NDC, 2022) submitted in the Paris agreement for all world regions. On top of that we implement, separately, the two different anti-leakage policies in the EU coalition: the EU CBAM and OBA.

Compared to a scenario without any anti leakage policies we find that the effects of introducing CBAM are positive for the EITE sectors in EU, except for non-ferrous metals and a minuscule decrease in output of paper products. That is, the output of non-ferrous metals and paper products decreases following implementation of CBAM to curb carbon leakage. In the OBA scenario, the activity in all OBA sectors increase and, as in the case with CBAM, the effects differ between the industries.[5] Key determinants for the differences are the sectors' initial emission intensities and their use of intermediates as input factors (of which prices are affected by the anti-leakage policies). Comparing industrial effects under OBA with the CBAM, we find that specifically output of non-ferrous metals, refined petroleum products, iron and steel and chemical products are larger under OBA than in the CBAM case.

Böhringer et al. (2015) use a numerical CGE model to examine the impacts a carbon tariff has on domestic EITE industries. They show that the carbon tariffs can be harmful to domestic EITE industries, in particular small open economies with significant shares of EITE industries. Whereas Böhringer et al. (2015) focus on Switzerland and the United States, their analysis includes a sensitivity analysis where EU and selected countries (separately) implement import tariffs on carbon. In contrast, our paper focuses on EU's climate coalition and the effect on selected countries as members of that coalition. In general, our numerical results are in line with Böhringer et al. (2015). However, they find that carbon tariffs reduce leakage and has a positive effect on output for all sectors in the EU (except for a very small increase for pulp and paper), but carbon leakage increases for several EITE sectors in Norway. Whereas we also find a decrease in output from paper products, albeit a very small one, the sector that is most adversely affected by CBAM in our analysis is non-ferrous metals.

There are several differences between the present paper and Böhringer et al. (2015) that explain the different results and our contributions to the literature: (*i*) differences in the CGE modeling, data, and our focus on a reference simulation for 2030; (*ii*) the implementation of the global NDCs in our

[5] In this paper we model CBAM and OBA such that the sectors covered by the CBAM includes all the sectors covered by the OBA (i.e., the EITE sectors) plus electricity generation, see Table 3.1 for details.

simulation, which affects the CBAM tariff; and (*iii*) we keep the EU emission cap constant and exogenous. In contrast, Böhringer et al. (2015) adjust the cap on domestic emissions to keep global emissions constant to facilitate welfare analysis. This implies feedback from the anti-leakage instruments to the stringency of the emissions cap in Böhringer et al. (2015).

We also find that the EU CBAM rate tends to be higher on goods imported from less developed countries, as these countries tend to have weaker greenhouse gas emissions regulation and thus low CO_2 prices, as compared to more developed countries. This may be a source for concern, as the EU CBAM may be particularly hard on imports from less-developed countries (Perdana and Vielle, 2022).

The paper is organized as follows: In Section 2 we present a theory model that highlights the effects at work when introducing CBAM or OBA on EITE goods. Section 3 presents the numerical CGE model and data, Section 4 the policy scenarios and Section 5 the numerical results. Section 6 concludes.

2. Stylized Theoretical Model

This illustrative theory model considers effects on domestic emission intensive and trade-exposed (EITE) firms of introducing (*i*) output-based allocation (OBA) or (*ii*) the carbon border adjustment mechanism (CBAM). Both instruments are assumed to be applied on the domestic EITE sectors only. The primary goal with this simple theory model is to build economic intuition about the industrial effects of the measures against carbon leakage, not to model foreign emissions and the leakage rates themselves (see e,g. Böhringer et al. 2017a,b; 2022, and Kaushal and Rosendahl, 2020, for more on measures against carbon leakage).

Suppose the firms receive free emission allowances proportional to production under OBA regulation. We let the value of free emission allowances per unit of production be given by *s*. Under CBAM we assume that there is a border tariff τ on imports of EITE goods. We assume that *s* and τ are exogenous. Hence, we have $s>0$ and $\tau=0$ under OBA regulation, and $s=0$ and $\tau>0$ under CBAM regulation.

Consider a competitive representative EITE firm with production given by $q=q(x)$, where *x* is use of a composite intermediate input factor with price $w(\tau)$. We assume that *q* is homogenous and positive, and that the production function $q(x)$ is concave and increasing in the input factor *x*. The price-taking firm sells a share given by $\alpha \in [0,1]$ of its product in the domestic market *d* and the remaining share $1-\alpha$ in the foreign market *f*, with producer prices $p(\tau,s)$ and p^f, respectively. We abstract from extra costs related to export, e.g. related to transport.

The domestic market equilibrium price $p = p(\tau,s)$ increases in the CBAM rate, because foreign supply of the EITE good to the domestic market decrease in the CBAM tariff. Hence, the derivative satisfies $\partial p / \partial \tau \equiv p_\tau > 0$. Further, we have $p_s \leq 0$ because the equilibrium price may decrease following an increase in production triggered by the OBA subsidy. The same reasoning applies to the price on input factors $w(\tau,s)$, where we have $w_\tau \geq 0$ and $w_s \leq 0$. Note that we allow for the case where the firm does not use EITE input factors, explaining that we have weak inequalities above.

We further assume that the foreign price satisfies $p_s^f \leq 0$ and $p_\tau^f \leq 0$, where a necessary condition for strict inequalities is that the domestic market constitutes a non-negligible share of the world market. The first weak inequality follows because domestic supply increases following the output subsidy *s*, and the fact that the equilibrium price does not increase when supply increases. The second weak inequality follows because the tariff τ makes it less profitable for foreign producers to export their goods to the climate coalition. This leaves a larger share of their goods available for sales in the non-coalition market, which again is not consistent with a higher price in the foreign market.[6] We will assume that the (absolute) values of p_s^f and p_τ^f are zero or very small in this model, reflecting that the foreign world market is big relative to the regulating region and the domestic market.

The price-taking firm's profit maximization problem is given by:

$$max_{x,\alpha}(\alpha(p+s)q(x)+(1-\alpha)(p^f+s)q(x)-wx), \quad s.t.\, 0\le\alpha\le 1. \tag{1}$$

The Lagrangian associated with the firm's maximization problem is:

$$L=\left(\alpha(p+s)+(1-\alpha)(p^f+s)\right)q(x)-wx-\lambda_1(\alpha-1)+\lambda_2\alpha, \tag{2}$$

where the λ's are the Lagrange multipliers. The solution is characterized by the following set of equations:

$$\begin{aligned}
&\partial L/\partial x=\left(\alpha(p+s)+(1-\alpha)(p^f+s)\right)q_x-w=0,\\
&\partial L/\partial\alpha=\left((p+s)-(p^f+s)\right)q(x)-\lambda_1+\lambda_2=0,\\
&\lambda_1\ \ge\ 0\ (\lambda_1=0\ if\,\alpha<1),\\
&\lambda_2\ \ge\ 0\ (\lambda_2=0\ if\,\alpha>0).
\end{aligned} \tag{3}$$

We see that an interior solution for α, which is characterized by $\lambda_1=\lambda_2=0$, requires that $p=p^f$. In this case we have

$$(p+s)q_x=(p^f+s)q_x=w \tag{4}$$

with any value $\alpha\in[0,1]$ and $\lambda_1=\lambda_1=0$ (α is not determined). Intuitively, the product price must be equal in the foreign and domestic markets for a solution where the firm sells in both markets, given our assumption of homogenous goods and zero transport costs (or similar mechanisms that cause

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[6]Böhringer et al. (2024) examine measures against carbon leakage in a general equilibrium context and show that OBA reduces the foreign price on EITE goods, and thereby foreign EITE production and emissions under reasonable assumptions.

different production costs of supplying the two markets).[7] One way to think of this is a situation where price-taking firms direct their product to the market with the highest price until the foreign and domestic prices are equal. Equation (4) implies that production increases in the product prices p and p^f, as well as the subsidy *s* under OBA, and decreases in the price of inputs *w* (remember that the production function $q(x)$ is concave).

We also have two corner solutions with $\alpha = 1$ ($\alpha = 0$) such that the firm only supplies the domestic (foreign) market. The corner solution with $\alpha = 1$, where the firm only supplies the domestic market, is characterized by:

$$(p+s)q_x = w, \tag{5}$$

with $\lambda_1 > 0$ and $\lambda_2 = 0$. This corner solution maximizes the firm's profits if the price in the domestic market is higher than the price in the foreign market, i.e. if we have $p > p^f$.

The other corner solution, where $p < p^f$, $\alpha = 0$, and the firm only supplies the foreign market, is characterized by:

$$(p^f + s)q_x = w, \tag{6}$$

with $\lambda_1 = 0$ and $\lambda_2 > 0$. Regardless of where the firm sells its product, the first order conditions state that the increase in marginal revenue equals the marginal cost with respect to the use of input factor *x*.

Consider the case of OBA regulation, where the firms receive free emission allowances with value *s* per unit of production (τ=0). It is straightforward to see from Equations (4) to (6) that production increases in *s*; i.e., production increases in OBA regardless of where the firm sells its product. The reason is that the free emission allowances constitute an implicit subsidy to production. That is, the more you produce, the more valuable free emission allowances you receive.

What about CBAM? Suppose first that the firm does not use EITE input factors, such that $w_\tau = 0$. Then the firm will not be much affected by the CBAM if we are in the corner solution where the firm

[7] The numerical model in Sections 3-5 features Armington goods (approximating heterogenous goods and/or transport costs).

only supplies the foreign market, cf. Equation (6). The reason is simply that the CBAM has zero or very small impact the foreign market where the firm sells its product.[8] Note that this contrasts with the result under OBA, which also benefits firms that export all their goods abroad. This changes if we assume that the firm sells all its output in the domestic market, in which case production will increase as the price for EITE goods in the domestic market increases (cf., Equation (5)). We see from Equation (4) that production increases with CBAM also in the interior solution, and note that CBAM may cause a shift from an interior solution to the case where the firm sells all its output in the domestic market (we may also have a switch from $\alpha = 0$ to $0 \leq \alpha \leq 1$).

Consider now the case where the firm use EITE input factors, such that $w_\tau > 0$. Then Equation (6) implies that a firm which sells all its output in the foreign market would reduce production if CBAM is introduced when $w_\tau > 0$. The reason is that the CBAM does not increase the price on output p^f, whereas the price on input factors W increases. A similar result may occur for firms that export a large share of their goods to the foreign market, e.g. because the domestic demand for their goods is very small. It follows that firms which utilize EITE goods in their production, and exports a large share of their product outside of the EU, might experience a decline in profits and reduce production when CBAM is introduced. This potential outcome may be relevant, e.g., for the aluminium industry; see Section 5.3 in the numerical section. Last, firms which sells much of their product in the domestic market face both a higher price on output and a higher price of EITE input factors when CBAM is introduced. Whereas the result on production is theoretically ambiguous in this case, the effect of output prices is arguably likely to dominate the effect of input prices, such that production increases when CBAM is introduced.

Table 2.1. Effects of OBA and CBAM on output from EITE firms (as compared to the case with no OBA or CBAM).

	OBA regulation		**CBAM regulation**	
	Low export share	**High export share**	**Low export share**	**High export share**
High EITE input	**+**	**+**	**+**[9]	**-**
Low EITE input	**+**	**+**	**+**	$\approx$**0**

[8] If $p_\tau^f < 0$ the firms will face lower prices on exports under CBAM, but the effect will be minor given the assumption that the regulating region is small compared to the world market.

[9] Table 2.1 assumes that the effect from increased product prices following CBAM dominates the effect of higher factor prices w.r.t. the EITE firm's output.

The above discussion is summarized in Table 2.1. It distinguishes between OBA and CBAM and assumes that firms sell a sufficiently large share of their product either at home or abroad to achieve an unambiguous result. It also distinguishes between whether the firm uses a sufficiently large share of EITE products as an input factor or not.[10] Note that domestic EITE firms increase production in all cases under OBA, whereas the results are more mixed with CBAM. Specifically, a domestic EITE firm that sells its product abroad and uses EITE goods as a factor of production will reduce output when CBAM is introduced.

[10] A high export share in Table 2.1. indicates low α in equation (4), or the solution in equation (6). Conversely, low export share indicates high α in equation (4), or the solution in equation (5). Similarly, high (low) EITE input indicates use of EITE such that w increases, i.e. $w_\tau > (\approx) 0$ in equations (4) to (6).

3. Data and method: The global SNOW model

We use the multi-region multi-sector computable general equilibrium (CGE) model called SNOW-Global (Yonezawa, 2024) to analyse the effects of OBA versus CBAM numerically. This model version is based on GTAP (Global Trade Analysis Project) data, which describes goods, sectors and associated emissions in detail. GTAP version 9 features national economic (input-output) accounts and bilateral trade flows for up to 140 regions and 57 goods (Aguiar et al., 2016). The database also reports associated energy flows and CO_2-emissions from fossil fuel combustion.[11]

3.1. Sector aggregation

The sectoral aggregation is essential for modelling anti-leakage policies and to distinguish energy goods by emission intensity and degree of substitutability (Fæhn and Yonezawa, 2021). The level of aggregation is a trade-off between real world realism and practical aspects such as data availability, model transparency and computational limitations. The sector aggregation in this paper is reasonably detailed regarding the sectors most directly impacted by the EU anti-leakage policies, whereas a higher level of aggregation is used for more peripheral sectors

We apply the anti-leakage policies to the EITE sectors that are all part of the EU ETS. Table 3.1 lists the sectors in our model (together with their three-letter acronym) and indicate which sectors are part of the EU ETS, the current system of free emission allowances (OBA)[12], and the EU Carbon Border Adjustment Mechanism (CBAM). Note that aluminium is in the non-ferrous metals category, cement is in non-metallic mineral products, and fertilizers are in chemical products. See Table A.1 in appendix A for sector details. The CBAM will be extended to cover more sectors in the future.[13]

[11] Note that GTAP 9 lacks information on CO_2 process emissions (see also Bednar-Friedl et al., 2012).

[12] See Section 3.7.

[13] The European Parliament (2021) has three key assessment criteria for the sectoral scope of a CBAM: (i) relevance in terms of greenhouse gas emissions, both with respect to direct and indirect emissions, (ii), exposure to a significant risk of carbon leakage, and (iii) practical feasibility aspects. According to the European Commission (2023), a review of the CBAM's functioning during its transitional phase will be concluded before the entry into force of the definitive system. At the same time, the product scope will be reviewed to assess the feasibility of including other goods produced in sectors covered by the EU ETS in the scope of the CBAM mechanism, such as certain downstream products and those identified as suitable candidates during negotiations. The report will include a timetable setting out their inclusion by 2030.

Table 3.1 Sectors and regulations

SNOW sector	ETS	OBA	CBAM
Coal (col)	X		
Crude oil (cru)	X		
Natural gas (gas)	X		
Electricity (ele)	X		X
Emission-Intensive and Trade-Exposed (EITE)			
Refined petroleum products (rpp)	X	X	X
Non-ferrous metals (nfm)	X	X	X
Iron and steel (i_s)	X	X	X
Non-metallic mineral products (nmm)	X	X	X
Chemical products (crp)	X	X	X
Paper products – publishing (ppp)	X	X	X
Air transport (atp)	X		
Water transport (wtp)			
Other transport (otp)			
Agriculture (agr)			
All other manufacturing (mfr)			
Services (ser)			

The non-ETS (NETS) sectors are aggregated into five main sectors: water transport, other transport, agriculture, all other manufacturing, and all other services (see Fæhn and Yonezawa, 2021).

3.2. Regional aggregation

The regional aggregation is sufficiently detailed to reflect the main trading partners for EU. The regional aggregation is as follows:

- Africa (AFR)
- Australia and New Zealand (ANZ)
- Brazil (BRA)
- Canada (CAN)
- China (CHN),
- Europe: EU27 and EFTA[14] (EUR)
- India (IND)
- Japan (JPN)
- South Korea (KOR)
- Middle East (MEA)
- Other Americas (OAM)
- Other Asia (OAS)
- Rest-of-Europe (ROE)
- United Kingdom (GBR)
- United States (USA)

[14]The EFTA members are Iceland, Norway, Switzerland and Liechtenstein, see https://www.efta.int/. They all have climate policy agreements with EU.

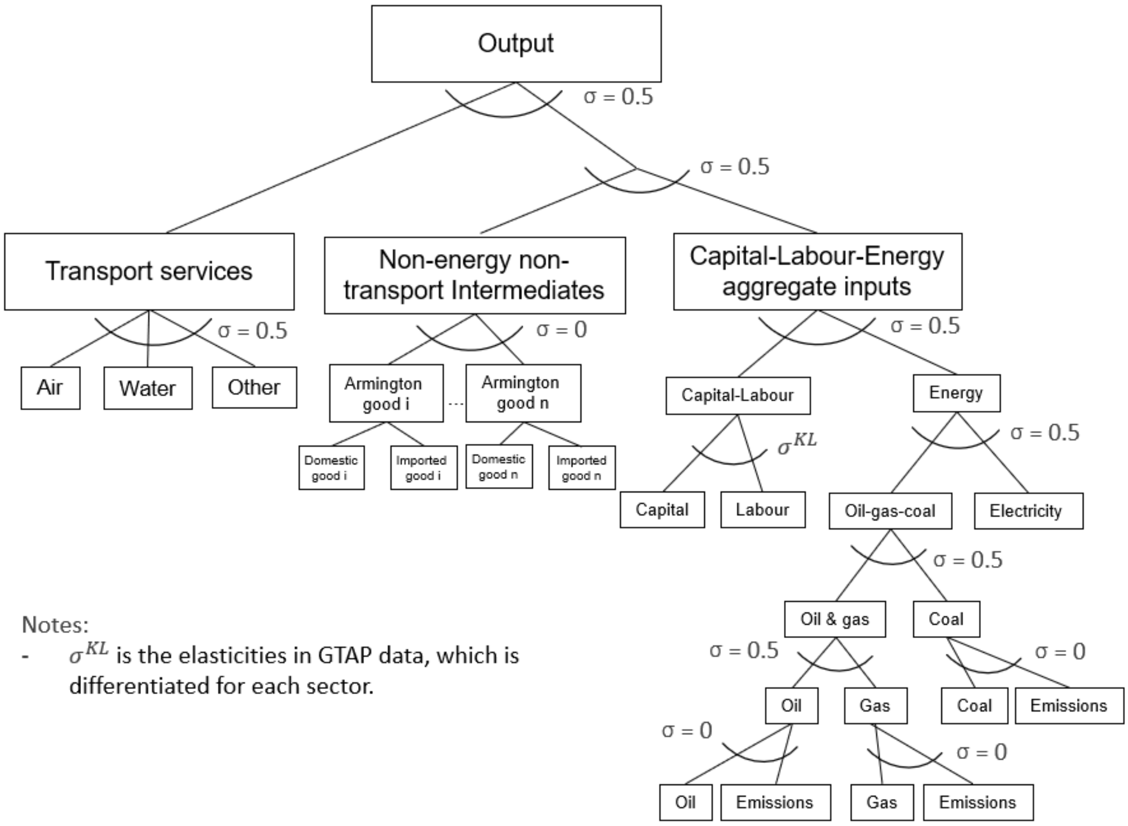
3.3. Non-technical SNOW model summary

The SNOW-Global model is a computable general equilibrium (CGE) model specially developed to quantify the economic impacts of environmental and climate policies.[15] The economy-wide setting accounts for supply and demand reactions of economic agents in a comprehensive manner and are based on empirical data. Particularly important in our context are the price-responsive input-output relationships among firms that transmit cost effects across industries, countries and regions. The multi-sector, multi-region CGE framework enables us to address policy impacts on global emissions and carbon leakage, industry-specific competitiveness and trade patterns, as well as global cost-effectiveness and economic incidence of EU's unilateral emissions regulation. The SNOW-Global model incorporates the economic incentives for representative firms outside the main regulated regions (in this case, EUR). Different versions of the model have been used in climate policy analyses in recent years, including carbon tariffs, see for example Böhringer et al. (2017a) and Fæhn and Yonezawa (2021).

Factor and commodity markets within each region are characterized by perfect competition. Primary factors of production include labour, capital and fossil fuel resources. Labour and capital are intersectorally mobile within a region, but immobile between regions. Fossil fuel resources are specific to fossil fuel production sectors in each region.

[15] SNOW-Global is programmed in GAMS/MPSGE (GAMS, 2020; Rutherford, 1999). The MPSGE framework uses CES nesting structures, see Böhringer et al. (2017a), appendix A for an example of an algebraic model summary quite similar as SNOW-Global. The model is documented in Yonezawa (2024).

Figure 3.1. The CES nest production structure of SNOW-Global for non-resource specific industries



Production in each industry and each region is represented by a representative firm technology. Firms producing commodities and primary fossil fuels are modelled with nested constant elasticity of substitution (CES) cost functions describing the price-dependent use of capital, labour, energy and materials (see Figure 1). At the top level, output is generated as a composite of transport commodities, and non-energy related intermediates that trades against an aggregate of energy, capital and labour. At the second level, a CES function describes the substitution possibilities between intermediate demand for the energy aggregate and a value-added composite of labour and capital. At the third level, there is substitution between capital and labour, and substitution in the energy related composite of coal, gas, oil, and electricity. The next three levels describe the substitution possibilities between different fossil fuel energy.

In the production of fossil fuels these industries have a natural resource factor added at the top of the nesting (see Figures A.3- A.4 in the Appendix). The elasticity of substitution of the resource factor is calibrated such that the supply elasticities of the fossil fuel extraction firms obtain relevant values (see Fæhn and Yonezawa, 2021). Particularly, the elasticity of substitution of the resource factor (σ^e) is calculated such that:

$$\sigma^r = \varepsilon \frac{\theta}{(1-\theta)}$$

where θ is the cost share of the resource factor and ε is the own-price elasticity of demand based on empirical estimates (see Fæhn and Yonezawa, 2021). All inputs except for the sector-specific fossil fuel resource are aggregated in fixed proportions. The GTAP database offers information of substitution possibilities in production between primary factor inputs. Specifically, the fossil fuel supply elasticities serve as the foundation for the elasticities of substitution in the fossil fuel extraction industries. Graham et al. (1999) and Krichene (2002) estimate these elasticities to be 4 for coal and 1 for crude oil and natural gas, respectively.

Final consumption demand in each region is determined by the representative agent, who maximizes utility subject to a budget constraint with fixed investment and exogenous government provision of public goods and services. Total income of the representative agent consists of net factor income and tax revenues net of subsidies. Consumption demand of the representative agent is given as a CES composite that combines consumption of the composite energy and an aggregate of other (non-energy) consumption goods. Substitution patterns within the energy bundle as well as within the non-energy composite are reflected by means of CES functions.[16]

Bilateral trade is specified following the Armington's differentiated goods approach, where domestic and foreign goods are distinguished by origin (Armington, 1969). Prices of goods may then develop differently among regions. All goods used on the domestic market in intermediate and final demand correspond to a CES composite that combines the domestically produced good and the imported good from other regions. The base-year trade deficit/surplus is kept constant for each region between the scenarios to ensure that the current account/balance of payment is constant. The Armington elasticity estimates in our model are taken from the GTAP database. CO_2 emissions are linked in fixed proportions to the use of fossil fuels, with CO_2 coefficients differentiated by the specific carbon content of fuels. CO_2 emissions abatement takes place by fuel switching (interfuel substitution) or energy savings (either by fuel to non-fuel substitution or by a scale reduction of production and final consumption activities).

[16] The nested CES structure for consumption is as in figure A.4, but without labour and capital input.

4. Policy scenarios

We simulate the following carbon policy scenarios for the year 2030 (see details below):[17]

- **NOLEAK:** A scenario with the EU ETS emission trading system, but no policies to mitigate carbon leakage (i.e., no OBA or CBAM).
- **CBAM**: A scenario that introduces CBAM into NOLEAK. This is closest to the intended EU proposals of the Parliament and the Commission.
- **OBA**: A scenario that introduces OBA into NOLEAK, i.e. the current anti-leakage policy measure OBA is continued.

The only difference between NOLEAK and the two policy scenarios (CBAM and OBA) is the presence of the anti-leakage policies. The NOLEAK scenario is included to identify the isolated effects of OBA and CBAM. We measure the effects of the two policy scenarios as percentage changes from the NOLEAK simulation. The effects following the shift from OBA to CBAM are derived by comparing the relative performances of these instruments in the OBA and CBAM scenarios. As such, NOLEAK serves as the benchmark reference scenario in this paper. See Table 3.1 for the policies' sector coverage.

The global SNOW model is a static model, and we create the benchmark dataset of 2030 through forward calibration in line with Fæhn and Yonezawa (2021). The effects and costs of climate policies in the years to come depend crucially on the chosen reference, or more precisely, the economic and emission projections. Following the approach of Fæhn and Yonezawa (2021) we simulate a benchmark scenario for the year 2030, incorporating projections of future GDP growth, energy demand, energy prices, and corresponding CO_2 emissions from the International Energy Outlook (IEO) 2017 (EIA, 2017). The following climate policies are included in the 2030 NOLEAK scenario: [18]

- The Paris agreement for global emission reductions in 2030: We implement the updated Nationally Determined Contributions (NDC, 2022) from 2020-2022 for all regions and countries.
- The EU Emission Trading Scheme (ETS): Sectors located in EUR trade emission allowances in EU ETS (see Table 3.1 for EU ETS sector coverage).
- Climate policies in non-ETS sectors in EUR: Non-ETS sectors in EUR trade emission allowances internally such that EUR achieves its climate goals.

Given these climate policies, we compute regional CO_2 prices for the year 2030. For the EUR, two CO_2 prices are calculated: one price in the ETS sectors and one price in the non-ETS sectors. Regarding other regions and countries, the NDCs are achieved by assuming domestic (regional)

[17] We also simulate a fourth scenario, equal to NOLEAK but without the EU ETS. This is only used to quantify leakage in NOLEAK.
[18] We assume that the income from quota sales in ETS is returned to the representative household in each modelled region.

quota markets that give a single CO_2 price in each region or country. Under these assumptions, the model generates a quota price of $197 per ton CO_2 (in 2023$) in the EU ETS. The CO_2 prices in regions outside EUR vary, ranging from nearly zero in regions with unambitious NDCs to EU ETS price levels for regions with stringent NDCs, see Figure A.2 in the Appendix.[19]

In the policy scenarios (CBAM and OBA) the regional CO_2 prices are exogenous and given from the NOLEAK scenario. The region-specific calculated CBAM tariff rates on the imported goods to EUR in *the CBAM scenario* equals the difference between the EU ETS price and these regional CO_2 prices.[20]

The aim of the CBAM is to level the playing field and limit carbon leakage by equalizing the cost of carbon emissions associated with domestic and foreign production of EITE goods. Two key factors determining the CBAM rate are emission intensities and the price of emissions. The CBAM may be based on an average of domestic sectoral emission intensities or, if the necessary information is available, foreign firm- or region-specific emission intensities (Böhringer et al., 2017a). Whereas CBAM based on foreign emission intensities may be more precise and give incentives for foreign emission reductions as a means to reduce the CBAM tariff, it may also cause a reshuffling where relatively clean producers export to the EU while dirty producers export elsewhere (Böhringer et al., 2017a). In this paper, the CBAM rates are calculated using product specific direct emission intensities and region-specific carbon prices based on the NDCs (NDC, 2022). As stated above, the modelled tariff is the difference between the EU ETS price and the CO_2 price in the production specific region. Hence, the carbon tariff will be relatively high on imports from regions with unambitious NDCs (and low carbon prices), and vice versa.

Last, we simulate a scenario with the current EU practice of free allocation of emission allowances (OBA) to EITE sectors in EUR, *the OBA scenario*. We assume that the OBA rate is set to 100 percent, such that OBA firms would receive all their emission allowances for free if they behaved exactly like they did in the NOLEAK scenario also in the OBA scenario.[21]

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[19] The CO_2 prices range from $7 to over $300 per ton CO_2 (in 2023 $). Many countries use CO_2 taxes as climate policy instruments instead of imposing a cap on CO_2 emissions, supporting the assumption of given carbon prices in other regions.

[20] Technically, this implies a shift from quantity-based (CO_2 emissions trading) to price-based (CO_2 tax) regulations in all regions outside EUR in the policy scenarios. The reason is that we need to model quantity-based regulation to calculate the regional CO2 prices implied by the emission reduction pledges under the Paris agreement (NDC, 2022). The switch from quantity based to price-based regulation endogenizes global emissions, while still retaining the approximate ambitions in the respective regions NDCs. See the appendix for more details on the NOLEAK scenario.

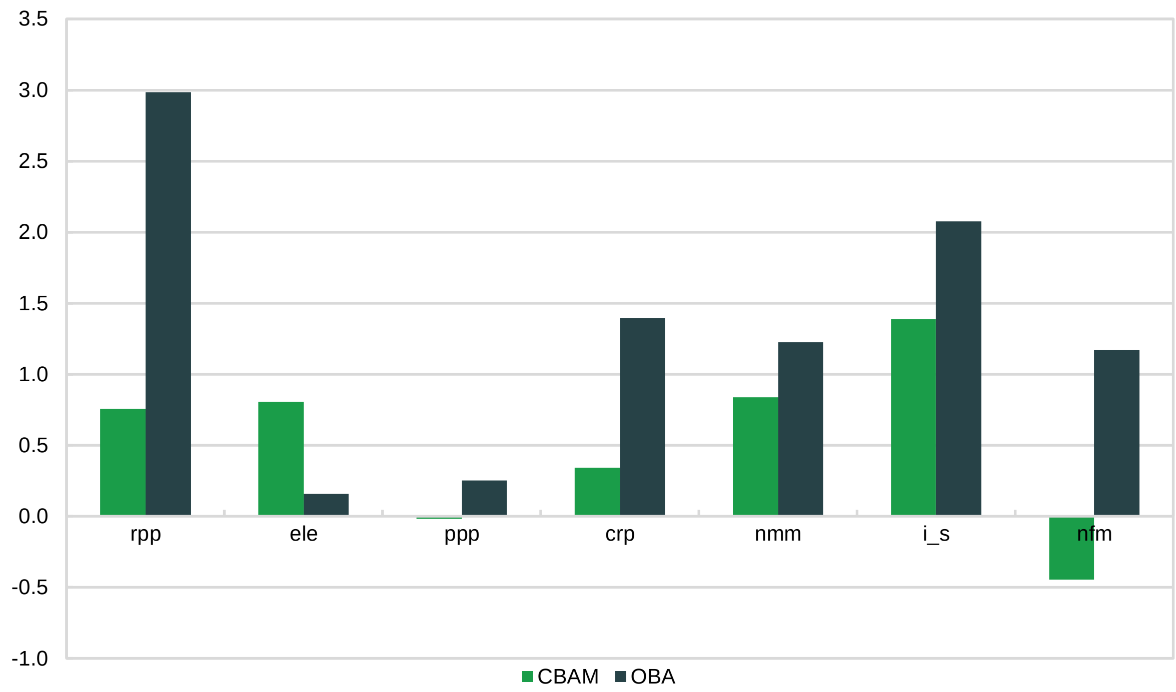
[21] EU currently allocates 100 per cent free quotas for the 10% best performing firms in the EITE sectors, and less for less effective firms. For less exposed sectors, free allocation is foreseen to be phased out after 2026. The list of sectors deemed to be at the risk of carbon leakage was updated in 2019 and will be valid for the period 2021-2030. For details, see https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019D0708&from=EN

5. Simulation results

5.1. Industrial effects

Figure 5.1 graphs the effects CBAM and OBA have on output in the EUR CBAM sectors (see Table 3.1) in 2030. Detailed results are given in Table 5.1. Positive numbers in Figure 5.1 indicate that output increases relative to the NOLEAK scenario.

Figure 5.1. Changes in output. % relative to NOLEAK (CBAM sectors, EUR, 2030)



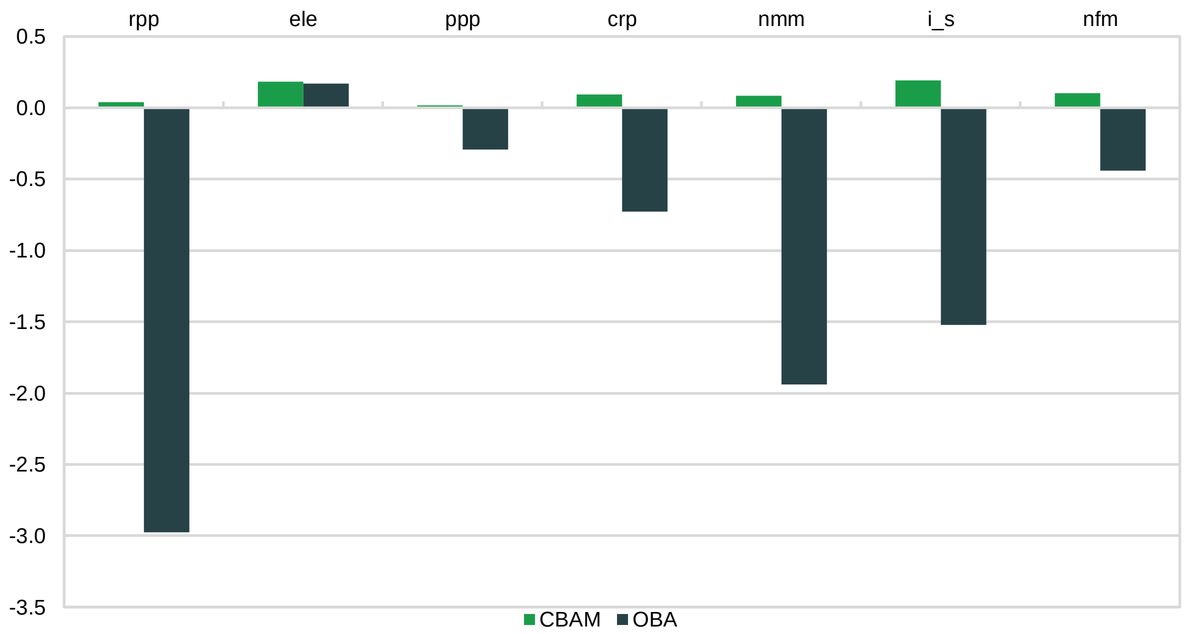
Introducing CBAM helps counteracting the negative effects of the EUR's climate policy on output levels and labour in the CBAM sectors. The reason is that imports of goods subject to CBAM now face carbon tariffs if they do not have a sufficiently strict carbon policy, which makes foreign goods less competitive in the domestic EU market compared to NOLEAK. The output effects are positive for all CBAM sectors, except for non-ferrous metals (nfm) and a microscopic decline in paper products and publishing (ppp). Specifically, whereas output of non-ferrous metals declines with 0.4 per cent, refined petroleum products (rpp) is 0.8 per cent higher, iron and steel (i_s) 1.4 per cent higher and non-metallic minerals (nmm) 0.8 per cent higher than in the NOLEAK scenario (see Table 5.1 for sector details).

Introducing OBA targets leakage by allocating valuable emission allowances to EITE industries proportional to output. We see in Figure 5.1 that the effects of OBA on domestic output are particularly large for refined petroleum products and iron and steel, with output increases of 2.9

and 2.1 percent relative to NOLEAK, respectively. Electricity (ele) does not receive free emission allowances under OBA (cf., Table 3.1), but still has an output increase with OBA (albeit much less than under CBAM).

Figure 5.2 graphs the effects OBA and CBAM have on output prices in EUR as compared with the NOLEAK scenario. Figure 5.2 highlights a key difference between OBA and CBAM: the output subsidy implicit in OBA *reduces* prices on goods produced by the firms receiving free emission allowances, whereas the import tariff under CBAM *increases* the domestic prices on CBAM goods. The exception is the electricity price, which increases under OBA. The reason is that the electricity sector does not receive free emission allowances, and that demand for electricity increases as EITE sectors increase their production under OBA. Whereas the changes in prices are caused mainly by the import tariff under CBAM, the magnitude of the effects on prices under OBA reflects the changes in output induced by OBA (i.e., the prices on OBA goods fall because the supply increase with the implicit subsidy to output constituted by the free emission allowances under OBA). For example, OBA causes a relatively large increase in production of refined petroleum products (rpp) and a corresponding relatively large decline in prices on refined petroleum products under OBA. The magnitude of the price change under OBA also depends positively on the market shares the EUR firms have in the European output markets.

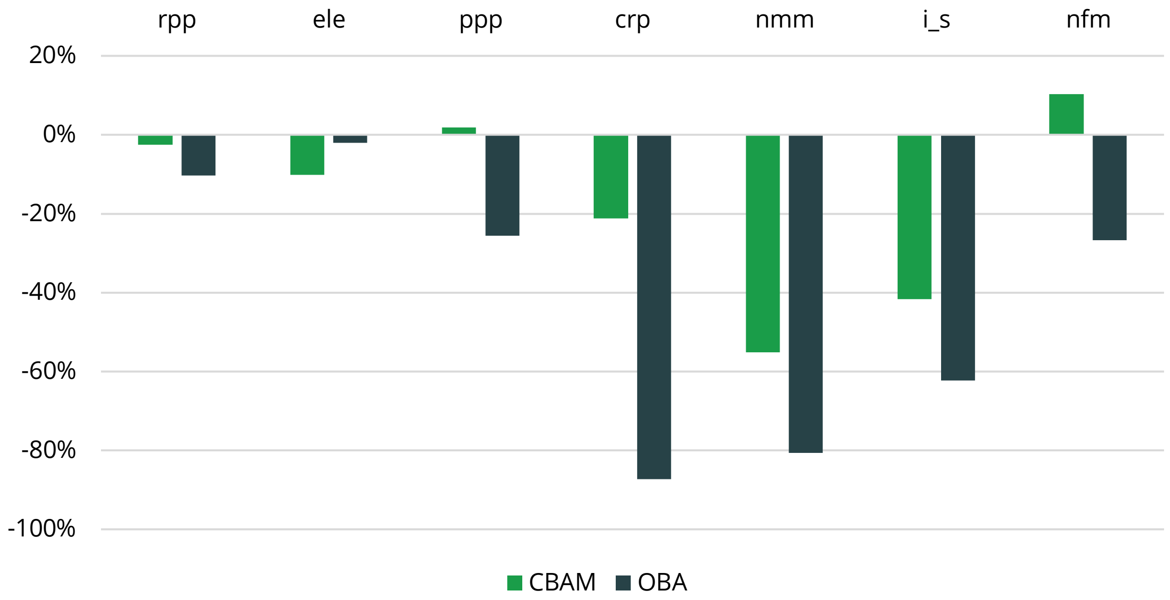
Figure 5.2 Change in output prices in EUR. % relative to NOLEAK (CBAM sectors, 2030)



How good are OBA and CBAM to ameliorate the decline in output in EUR caused by the emissions pricing? Figure 5.3 shows how OBA and CBAM limit the output reduction across the various sectors.

For example, OBA reduces the fall in output caused by domestic emission pricing in chemical products (crp) by more than 80 per cent, while CBAM reduces the output decline with around 20 per cent.

Figure 5.3. Mitigation of "output leakage" caused by emission pricing. Measured in per cent of the output reduction caused by emission pricing in NOLEAK (EUR, CBAM sectors, 2030)

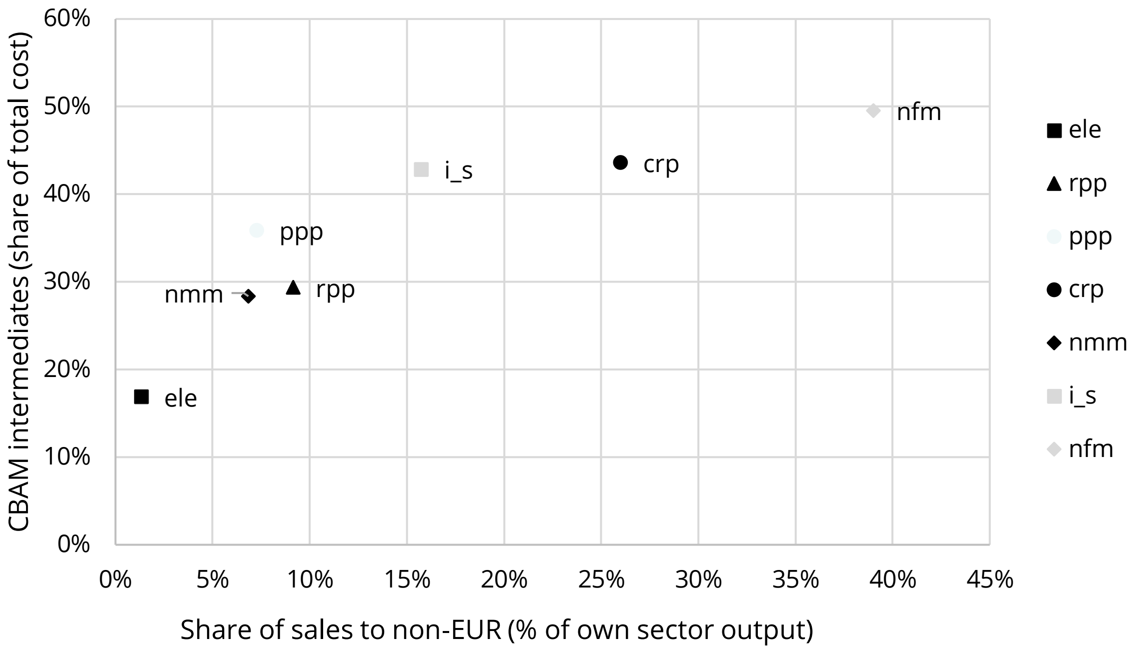


Note that large negative effects in Figure 5.3 implies that the policy is effective in reducing the decline in output following the emission pricing. Specifically, a value of -100 per cent would indicate that the anti-leakage measure completely neutralizes the fall in output that results from emission pricing.

Figures 5.3 indicates that OBA is more effective at mitigating domestic output reduction than CBAM. This can be explained by two mechanisms identified in the theory section: Firstly, firms receive valuable free emission allowances under OBA for all their output, including the goods sold abroad (outside the EUR coalition). In contrast, firms only benefit from the higher output prices caused by CBAM on the share of output sold in the domestic (EUR) market. Secondly, CBAM entails higher prices on CBAM input factors, which in isolation pulls in the direction of lower production. This mechanism is not present under OBA. On the contrary, the prices on OBA input factors decrease under OBA.

These relationships are graphed in Figure 5.4, where CBAM is expected to be less favourable as we move up and to the right. Note that Figure 5.4 gives the cost of input factors under NOLEAK as a share of total production cost, which also includes e.g. labour and capital cost (the shares are very similar in the CBAM and OBA scenarios).

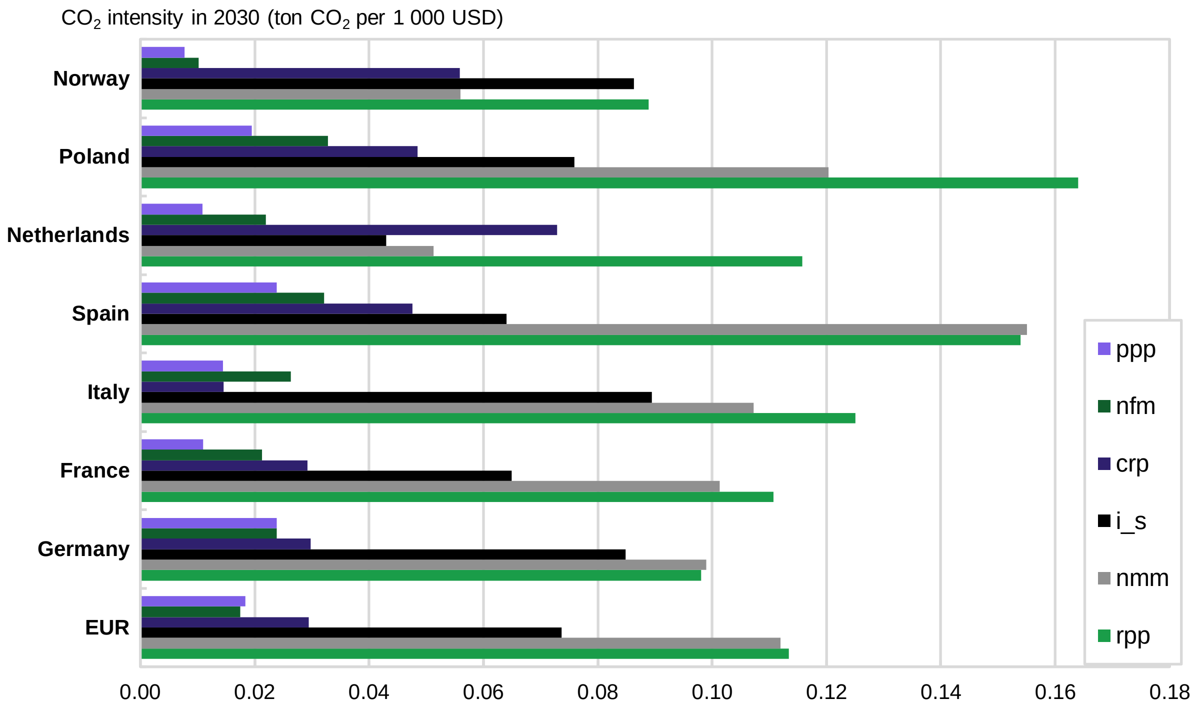
Figure 5.4 Export shares and use of CBAM intermediates (CBAM sectors, NOLEAK, 2030)



We observe that the use of intermediate goods from the CBAM sectors as input factors is particularly large in non-ferrous metals (nfm), and to a somewhat lesser extent in chemical products and fertilizers (crp) and iron and steel (i_s). Combined with nfm's relatively large export to markets outside of EUR, this is an important reason why CBAM has a negative impact on production of non-ferrous metals (see Figure 5.1). In terms of the theory model, nfm is an example of the case with high export shares and large use of intermediate CBAM input factors, implying that CBAM has a negative impact on production (upper right corner in Table 2.1). The output responses in the numerical simulations are also determined by other factors, including supply elasticities, substitutability between goods in consumption and production, and general equilibrium effects like changes in labour and capital costs (wage rate and rate of return on capital), see Table 5.1. Such macroeconomic effects are discussed in more detail in Section 5.2.

The results show that the effect of CBAM and OBA varies markedly across sectors. Besides the above-mentioned issues like export shares and use of CBAM goods as input factors, the sectoral impact of implementing the anti-leakage policies in general increases in sectors with higher initial emission intensity. Under CBAM, the reason is that the import tariff increases with the emission intensity. Similarly, under OBA, the amount of free emission quotas received per unit produced is proportional to the sector's emission intensity. Hence, the magnitudes of both anti-leakage policies are proportional to emission intensities. Figure 5.5 graphs the emission intensities of the energy intensive and trade exposed (EITE) sectors in EUR and some selected European countries.[22]

Figure 5.5 CO_2 intensity (metric ton CO_2 per $ 1 000 output) for EUR and selected EUR countries, reference simulation in 2030.[a]



[a] See Table 3.1 and Section 3.3 for sector and region abbreviations

Specifically, refined petroleum products (rpp), non-ferrous metals (nfm) and, to a somewhat lesser extent, iron and steel (i_s), have high emission intensities in EUR. This is consistent with the effects on output graphed in Figure 5.1.

Table 5.1 gives the effects on output, labour and emissions in the CBAM sectors under the two anti-leakage policies. The effect on labour mirrors the output effects and is positive for alle EITE industries except non-ferrous metals (nfm).

[22] The emission intensity of electricity production is 11 times that of the EITE average in EUR (see figure A.1 in the Appendix) and not included in figure 5.5.

Table 5.1 **Output and CO_2 emissions in CBAM sectors in EUR, per cent change from NOLEAK 2030.**

	CBAM			OBA		
	Output	Labour	CO_2	Output	Labour	CO_2
CBAM sectors	0.5	0.5	0.2	1.3	0.9	-0.2
Refined petroleum products (rpp)	0.8	0.8	0.1	3.0	2.4	3.7
Electricity (ele)	0.8	0.9	0.1	0.2	0.1	-1.6
Paper products – publishing (ppp)	0.0	0.0	-0.5	0.3	0.1	-0.2
Chemical products (incl. fertilizers) (crp)	0.3	0.4	0.1	1.4	1.2	1.7
Non-metallic minerals (nmm)	0.8	0.9	0.4	1.2	1.0	1.1
Iron and steel (i_s)	1.4	1.5	1.1	2.1	1.8	1.9
Non-ferrous metals (nfm)	-0.4	-0.4	-0.7	1.2	1.0	0.9

5.2. Global emissions and macroeconomic effects

Table 5.2 **Macroeconomic effects in EUR, per cent change from NOLEAK, 2030.**

	CBAM	OBA
GDP	0.01	0.06
Private consumption	0.04	0.06
Rental rate of capital	-0.04	0.21
Wage rate	-0.06	0.20

Effects on selected macroeconomic variables are given in Table 5.2. Not surprisingly, the effects of the anti-leakage policies on economy wide aggregates such as GDP and private consumption are very small. As mentioned in the theory section, demand for labour and capital increases due to higher activity in the OBA sectors when OBA is implemented. Hence, the wage rate and the rental rate of capital are higher under OBA as compared to the NOLEAK scenario, see Table 5.2. The isolated effect of this is increased production costs in all other sectors, and higher equilibrium prices on non-OBA goods. The effect is opposite under CBAM, where the import tariff reduces demand for labour and capital in the economy and the rental rate of capital and the wage rate are both lower compared to NOLEAK.

Note that the general equilibrium effects on the rental rate of capital and the wage rate tend to work in the opposite direction of the direct effects identified by the partial equilibrium theory model in Section 2. For example, we know from the theory and Figure 5.2 that prices on the input factors receiving free emission allowances decline under OBA. This increases the demand for labour and capital, which increases the wage rate and rental rate of capital under OBA. The opposite is the case for CBAM, where the carbon border tariff increases the prices on CBAM goods and induces a small decline in aggregate output and demand for labour and capital. This decline is reflected in a small reduction in the wage rate and rental rate of capital under CBAM, see Table 5.2. Hence, there is a tendency that the equilibrium effects in the labour and capital markets moderate the direct first-order effects of the carbon leakage policies, albeit to a very limited extent.

Table 5.3 ETS price ($) and global emission effects, 2030.

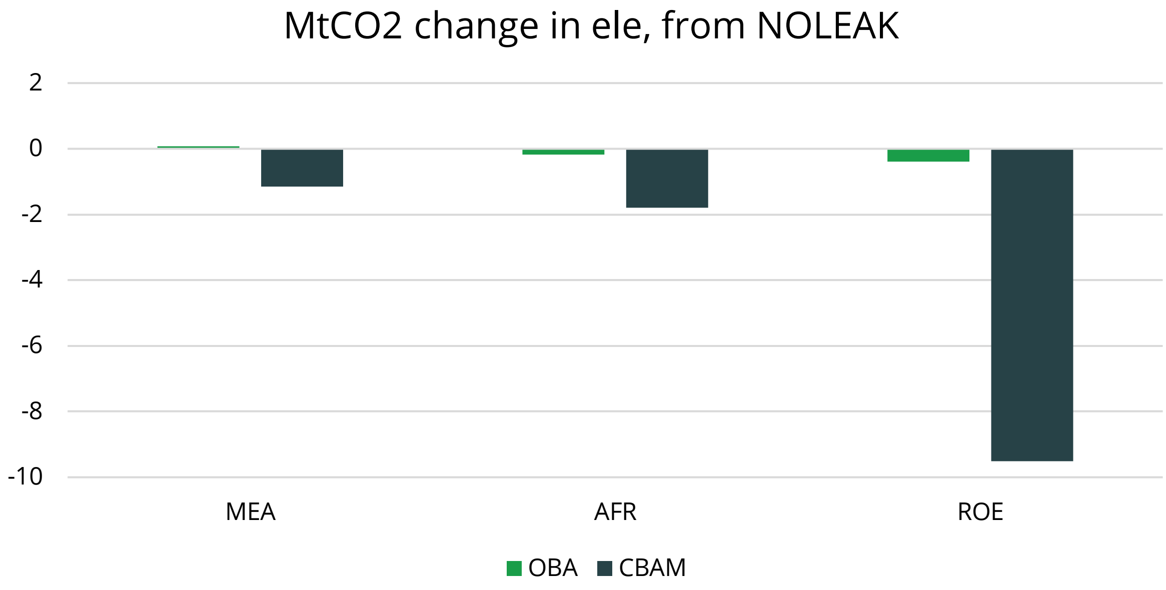
	NOLEAK	CBAM	OBA
EU ETS price	$197	$202	$205
Change in global CO2 emissions excl. EUR*		-24	-6

* $MtCO_2$ from NOLEAK

The carbon leakage rates are 12 per cent, 11 per cent and 10 per cent under NOLEAK, OBA and CBAM, respectively, and global CO_2 emissions excluding EUR are 24 and 6 $MtCO_2$ lower with CBAM and OBA compared to NOLEAK (see Table 5.3). Hence, whereas the anti-leakage policies have some effects on output in the targeted EITE industries (see, e.g., Figure 5.3), the effects on carbon leakage are modest. Nevertheless, the reduction in global emissions following a shift from NOLEAK to CBAM equals around 1.4 per cent of the total CO_2 emissions in EUR under NOLEAK. The moderate effects on global emissions reflect that EUR's share of global economy is relatively small and indicate that the anti-leakage policies are more effective at protecting domestic emission intensive and trade exposed industries than to reduce (global) emissions. The primary instruments for reducing EUR (domestic) emissions are the EU ETS and emission taxes.

That global emissions decline most under CBAM may be surprising, given the results in figures 5.1 and 5.3. After all, they show that OBA is more effective than CBAM in maintaining output levels in the EITE sectors. This implies lower activity levels in foreign EITE sectors under OBA as compared with CBAM, which again suggests lower emission levels abroad under OBA. So why are global emissions excluding EUR lower under CBAM? The reason is that the EU CBAM includes the very emission intensive electricity sector (ele), whereas OBA does not. The CBAM import tariff on electricity to EUR reduces electricity production outside of EUR. This electricity-market effect outweighs the above-mentioned EITE advantage OBA has with respect to reducing foreign EITE emissions, and thus global emissions are lower under CBAM in Table 5.3. We see in Figure 5.6 that it is primarily a decline in electricity imports from Eastern Europe (ROE) under CBAM that drives this result, as ROE's emissions related to ele production decrease by almost 10 $MtCO_2$ from NOLEAK.

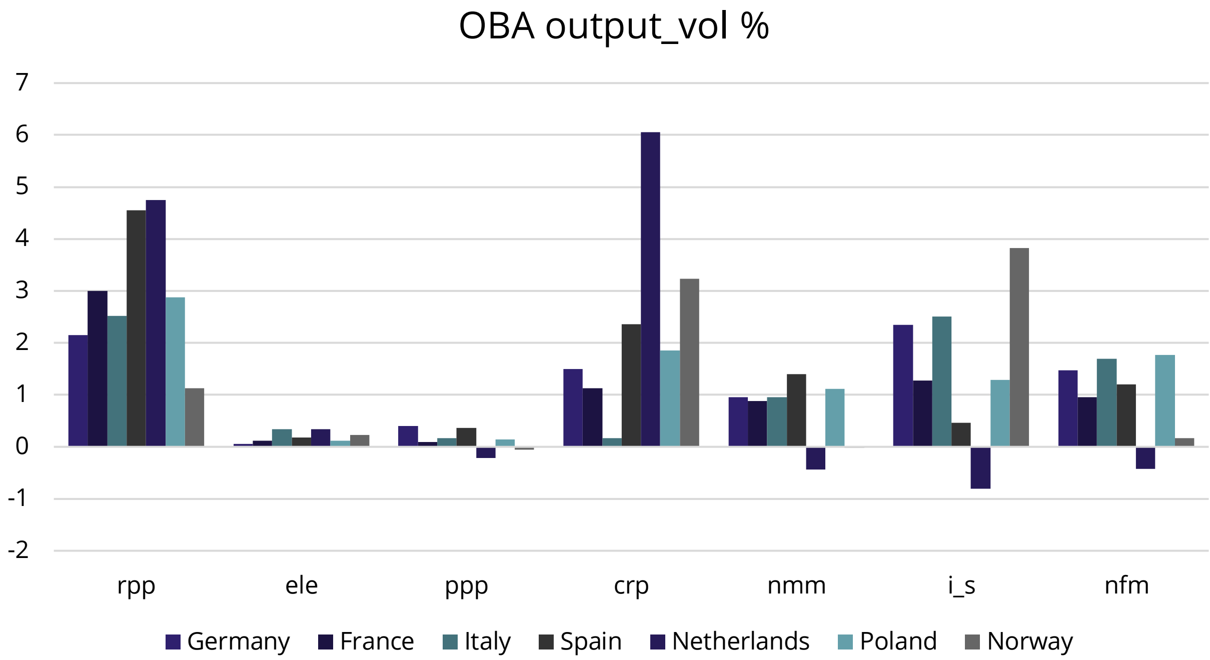
Figure 5.6 Change in million tCO_2 emissions from the electricity sector in EUR's neighbouring regions, changes from NOLEAK

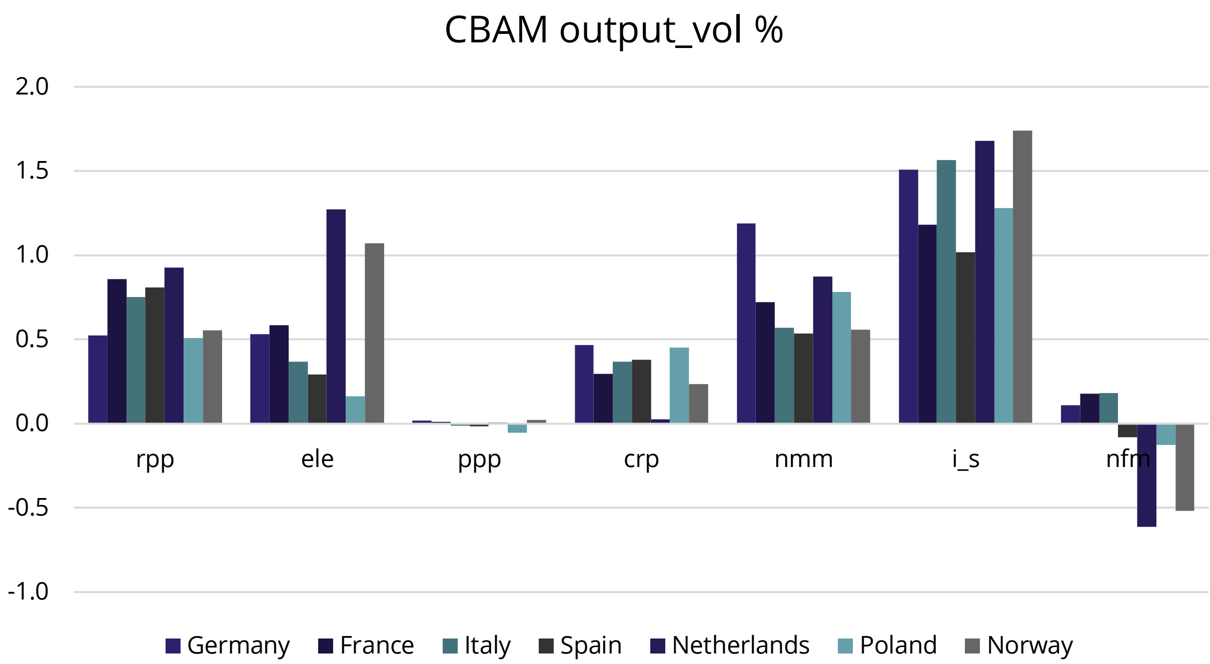


5.3. Industrial differences between EUR countries

Figure 5.7 depicts changes in output for the CBAM sectors in selected EUR countries. In general, the anti-leakage policies have positive effects on output in all countries. The one exception is the effects on non-ferrous metals (nfm) which is positive for France, Germany and Italy, but negative for Spain, Poland and Norway. We also observe that the relative magnitude differs substantially between industries and countries. The discrepancies across sectors and countries graphed in Figure 5.7 may contribute to explain the disagreement about transition from OBA to CBAM in the EU, both between countries and the various EITE industries (Wettestad, 2024). From a policy perspective, the results imply that the characteristics of the various EITE industries should be taken into account when considering measures against carbon leakage.

Figure 5.7 Output effects of anti-leakage policies, EITE-industries and selected EUR countries. Percentage change from NOLEAK, 2030.[a]





[a] See Table 3.1 and Section 3.3 for sector and region abbreviations

5.4. Sensitivity

The trade modelling in SNOW-Global assumes that products traded internationally are differentiated by the region of origin and the end users have preferences for a given bundle of these products (Armington, 1969). The Armington trade elasticity represents the elasticity of substitution between products produced in different regions. A higher trade elasticity implies that the goods are more substitutable, and thus become more exposed to trade and carbon leakage. The trade elasticities are therefore important for the effects of CBAM. We have performed a sensitivity where we double the trade elasticities for the ETS sectors in EUR (CBAM_HA-scenario). As expected, the effects of the different leakage policies are strengthened with increased preferences for trade, but the effects are quite small, see Table 5.4.

Table 5.4 Output and CO_2 emissions in CBAM sectors in EUR with higher trade elasticity, per cent change from NOLEAK 2030.

	CBAM		CBAM_HA	
	Output	CO_2	Output	CO_2
CBAM sectors	0.5	0.2	0.7	0.2
Refined petroleum products (rpp)	0.8	0.1	1.3	1.1
Electricity (ele)	0.8	0.1	1.1	-0.1
Paper products – publishing (ppp)	0.0	-0.5	0.0	-0.7
Chemical products (incl. fertilizers) (crp)	0.3	0.1	0.5	0.1
Non-metallic minerals (nmm)	0.8	0.4	1.6	1.0
Iron and steel (i_s)	1.4	1.1	2.6	2.1
Non-ferrous metals (nfm)	-0.4	-0.7	-1.3	-1.6

An overlap of CBAM and OBA is scheduled to happen during the transition (European Commission, 2023). We therefore simulate a HYBRID scenario, where we apply the carbon tariff only at a rate of 50 per cent, while the OBA rate is reduced to 50 per cent of the full rebate. For electricity a 100 per cent carbon tariff is introduced since they have no OBA initially.

Table 5.5 Output and CO_2 emissions in CBAM sectors in EUR with HYBRID scenario, per cent change from NOLEAK 2030.

	CBAM		OBA		Hybrid	
	Output	CO_2	Output	CO_2	Output	CO_2
CBAM sectors	0.5	0.2	1.3	-0.2	0.9	0.0
Refined petroleum products (rpp)	0.8	0.1	3.0	3.7	1.8	2.0
Electricity (ele)	0.8	0.1	0.2	-1.6	0.7	-0.7
Paper products – publishing (ppp)	0.0	-0.5	0.3	-0.2	0.1	-0.4
Chemical products (incl. fertilizers) (crp)	0.3	0.1	1.4	1.7	0.8	0.8
Non-metallic minerals (nmm)	0.8	0.4	1.2	1.1	1.0	0.7
Iron and steel (i_s)	1.4	1.1	2.1	1.9	1.7	1.4
Non-ferrous metals (nfm)	-0.4	-0.7	1.2	0.9	0.3	0.0

As shown in Table 5.5, the effects on the CBAM sectors lie in between those of the OBA scenario and the CBAM scenario for the sectors that have 100 per cent OBA (see also Table 5.1). The positive output effect on electricity is slightly lower than in the CBAM scenario, but higher than in the OBA scenario. Combined with smaller reductions in output in the sectors receiving OBA, aggregate output in EUR's CBAM sectors increase by 0.9 per cent compared to the NOLEAK scenario. Higher activity in the electricity intensive CBAM sectors has a positive effect on the demand and supply of electricity, compared to the CBAM scenario, see Table 5.3.

6. Concluding remarks

In this paper we have compared the effects of the EU scheduled CBAM with the currently implemented OBA. We have focused on the numerical effects at the industry level, and particularly the EITE industries covered by the CBAM. We have used a numerical, disaggregated, global CGE-model to analyse the EU 2030 carbon and anti-leakage policies. Compared to a scenario without any anti-leakage policies we found that the effects of introducing CBAM are positive for the EITE sectors in EUR, except for non-ferrous metals and a very small decrease in paper products. That is, the output of non-ferrous metals and paper products decreases following implementation of CBAM to curb carbon leakage. In the OBA scenario, the activity in all OBA sectors increase and, as in the case with CBAM, the effects differ between the industries. Key determinants for the differences are the sectors' initial emission intensities, how much they export to non-EU ETS areas, and their use of intermediates as input factors (of which prices are affected by the anti-leakage policies). Comparing industrial effects under OBA with the CBAM for the EUR, we find that specifically output of non-ferrous metals, chemical products and paper products are larger under OBA than in the CBAM case.

In general, we found that a firm which sells a large share of its output in the foreign market (outside of the EU) is more likely to reduce production following the transition from OBA to CBAM. The reason is that the CBAM does not affect the price on output in the foreign market whereas the price on imported input factors covered by the CBAM increases.[23] This differs from OBA, where the EITE firms receive free emission allowances regardless of where the product is sold.

The results indicate that OBA is more effective than CBAM in maintaining output levels in the EITE sectors. On the other hand, CBAM turns out to be more effective at reducing foreign emissions in our simulations. The reason is that CBAM also covers the very emission intensive power plants producing electricity.

While we find that OBA and CBAM have a modest effect on global CO_2 emissions and macroeconomic indicators (cf. Tables 5.2 and 5.3), the impact on activity levels in the EITE sectors is more significant. This is important because a key motivation of the EU climate coalition for introducing measures against carbon leakage, such as OBA or CBAM, is to limit the decline in industrial production induced by domestic emission pricing by levelling the playing field.

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[23] It is possible that the price on input factors decreases if the firm use very little CBAM goods as factors of production due to general equilibrium effects.

In this paper we have focused on the industrial effects of the EITE sectors. In this respect, it is important to remember that even though we generally find a larger increase in output under OBA as compared with CBAM, this does not necessarily imply that welfare is higher under OBA. After all, one of the key criticisms of OBA is that prices on EITE goods are artificially low under OBA because of the implicit subsidy constituted by the free emission allowances (e.g., Böhringer and Lange, 2005). Other factors, such as production and consumption of non-EITE goods, and overall economic efficiency, are important for determining welfare.

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Appendix A:

Figure A.1 Ton CO_2 intensity per 1 000 USD, 2030.

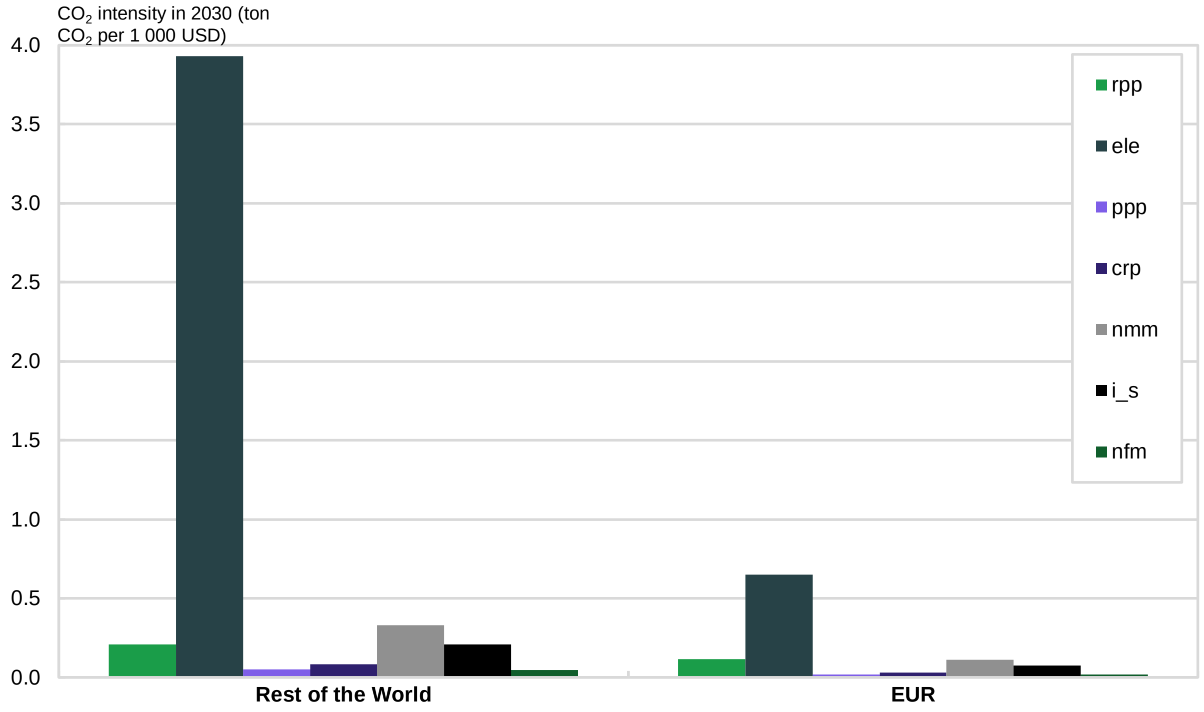


Figure A.2 Regional CO_2 price per metric ton CO_2, NOLEAK, 2030. Regions are listed in Section 3.2.[24]

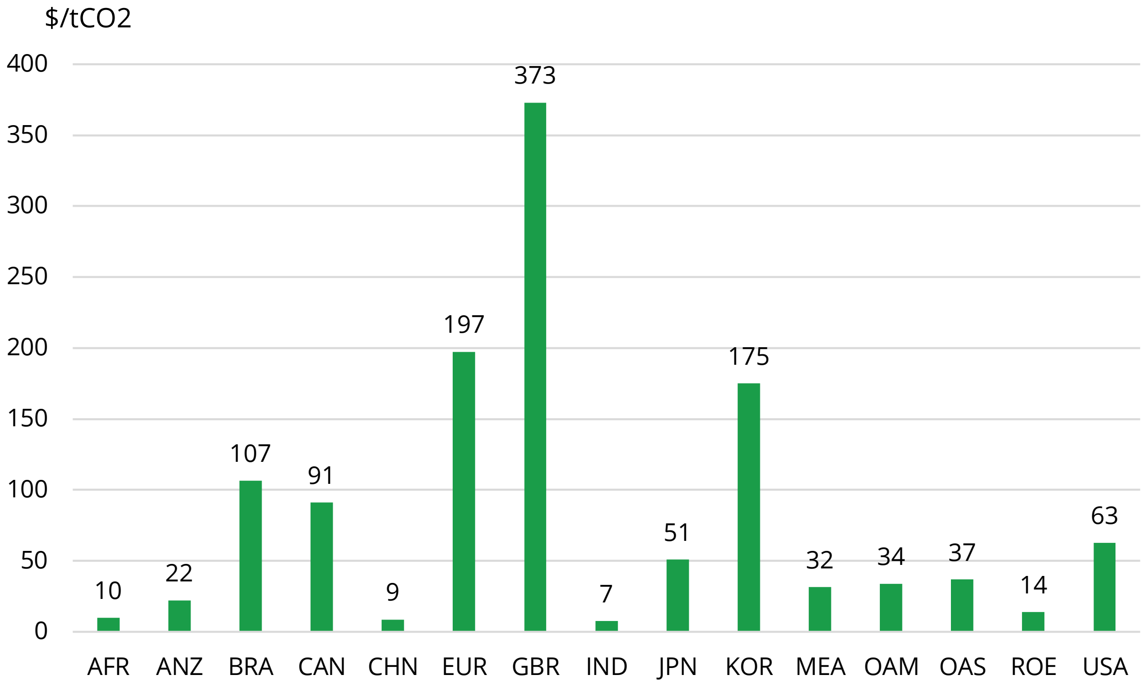
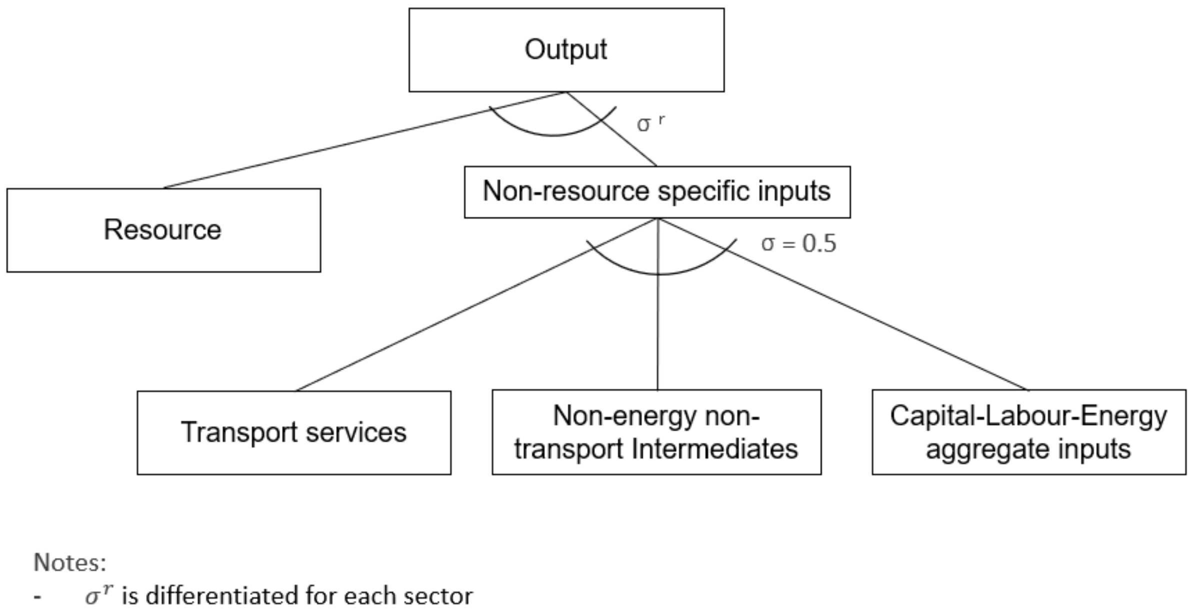


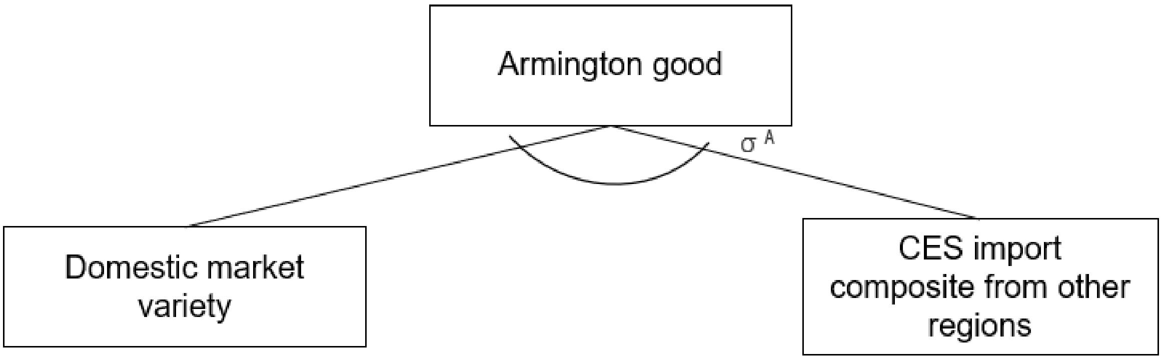
Figure A.3 Nesting in resource specific production



Note: CES is an abbreviation for constant elasticity of substitution.

[24] Given the ambitious NDCs for GBR, the simulated CO_2 price is very high. In the CBAM policy alternative we have assumed no tariffs on GBR goods to EUR.

Figure A.4 Nesting in Armington production



Notes:
- σ^A is differentiated for each sector according to GTAP data

Note: CES=constant elasticity of substitution.