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How to price CBAM permits: Combining the markets for ETS and CBAM carbon permits

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Abstract

The EU and the UK both control domestic greenhouse gas emissions through cap-and-trade systems – their Emission Trading Systems. To reduce 'carbon leakage' they propose to charge imports for emissions at the same price as domestic producers through Carbon Border Adjustment Mechanisms which take the domestic price and apply it to imports, without limits. We show that this approach could result in a technological improvement that reduces demand for domestic emissions increasing global emissions. We propose alternatively that domestic producers and importers should bid in the same capped market for emissions permits. We show that such an arrangement avoids the possible perversity just noted and implies lower global emissions for any given technological improvement.

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Non-Technical Summary

The European Union (EU) is in the process of introducing a Carbon Border Adjustment Mechanism (CBAM); the United Kingdom Government has announced its intention to do so. Both still have details to fill in, but the broad outlines are clear.

The CBAM's purpose is to eliminate 'carbon leakage' whereby domestic production is displaced by production from jurisdictions that have weaker restrictions on emissions. For sales in the EU, it aims to charge the same rate for emissions embedded in imports as in domestic production. By doing so, the CBAM is also "expected to effectively support the reduction of greenhouse gas emissions in third countries", contributing further to the EU's objective of reducing global warming.

The ETS, in both the EU and the UK, are cap-and-trade systems. The authorities declare a total acceptable emissions level for their domestic producers and issue the corresponding number of emission permits. Abstracting from a lot of details, in the EU the authorities will take the average price of ETS permits in the previous week and issue any number of CBAM permits for imports at that price. In the UK, the Government intends to make the CBAM akin to an indirect tax as imports enter the country, with the price determined by the price of domestic permits over the preceding quarter.

In both cases, importers and domestic producers would face approximately the same emissions price and hence the same incentive to abate emissions; this, in turn, ensures that abatement is achieved in the least-cost manner. However, in both cases, the price of emissions (permits) is determined not by EU or UK demand for the goods causing emissions but only by the demand for such goods that is met by domestic producers. Thus, the trade-off between emissions and other goods is in effect determined by only half the actors in the market: it is as if the price of milk was determined by purchases only by people who are lactose-intolerant who then impose this price on everybody else. Both the EU and the UK are substantial 'importers' of emissions so the treatment of imports is a substantive issue.

We propose to combine the markets for ETS and CBAM permits so that the price is determined by everyone buying and selling emissions-intensive goods in the EU (UK). This will allow government to determine the amount of emissions created by the absorption of goods in their jurisdictions rather than just by production, which seems more in consonance with achieving net-zero objectives. With full information, a government could set the number of permits for domestic production in their currently chosen approach such that it replicates the result of our proposal. But full information is impossible; moreover, circumstances constantly change, and the two approaches react differently as they do so.

One case of particular interest is if technical progress in the CBAM-country reduces the demand for emissions. Under current plans this would reduce the ETS permit price and hence the prices of CBAM permits and of imports and thus increase imports. The corresponding increase in production abroad would increase foreign emissions, possibly by more than the decline in emissions triggered by the original technical progress, in which case, despite emission-saving innovation, global emissions would increase.

Our paper provides a simple graphical demonstration of this danger. It then provides a more complete, albeit still simplified, general equilibrium model of the economy in which the perverse result just outlined can occur and provides simulations of the EU that suggest that it can occur with plausible ranges of parameters based on the iron and steel sector (the largest sector affected by CBAM). These simulations also show that, for any given improvement in emissions efficiency, our proposed combined market approach implies lower global emissions that does having separate ETS and CBAM markets. One aspect currently not fully specified is whether the

CBAM should entail rebating ETS costs on exports. The EU says it will but has not said how and the UK has yet to decide. We model outcomes with and without such a rebate. Finally, we discuss some of the practical challenges of combining the ETS and CBAM markets, all of which seem small relative to those of establishing the two markets in the first place.

Although the model and simulations should not be taken literally, this analysis suggests that for a relatively simple institutional change, the EU could place its emissions policy on a more secure footing and eliminate a possible perversity in its net zero policies.

The UK position, which still has details to settle, is discussed in an Appendix. The UK has agreed to combine its ETS with that of the EU, although, as yet, with no details, but currently does not appear to intend to combine its CBAM with the EU's. We argue that the latter combination would also make very good policy sense.

How to price CBAM permits: Combining the markets for ETS and CBAM carbon permits

Nicolo Tamberi and L Alan Winters[1]

The European Union (EU) is in the process of introducing a Carbon Border Adjustment Mechanism (CBAM): an information-gathering phase is already underway and the collection of emissions charges on imports is due to start (very gradually) in January 2026. Among many available summaries, see European Commission (2023) and European Commission (2025a) for the latest plans. The United Kingdom (UK) has now announced its intention also to introduce a CBAM with charges entering into force in 2027 – see Department for Energy Security & Net Zero (2023) and HM Treasury and HM Revenue and Customs (2024). Both the EU and the UK still have some details to fix but the broad outlines are reasonably clear. In May 2025, the UK and EU announced their intention to link their Emissions Trading Schemes (ETSs) but did not mention their CBAMs in that announcement – HM Government (2025). It seems likely that the two CBAMs will remain separate for now, although, as the Centre for Inclusive Trade Policy has argued frequently, there are material benefits to harmonising them – e.g. Lydgate (2024) and Zhang et al (2024). In the remainder of this paper, we will refer to the EU's CBAM, but the arguments apply equally to the UK's, despite the UK's efforts to differentiate its policy. We describe the UK's (current) position in a little more detail in the Appendix.

The logic of the CBAM is clear. The EU charges EU firms for the greenhouse gases they emit through its Emissions Trading System (ETS) and the CBAM is designed to charge similarly for the carbon embodied in imports. It aims to ensure that, for the products included in the CBAM's remit, every unit of EU consumption pays the same cost of emissions, whether domestically produced (through the ETS) or imported, (through the CBAM). This is an entirely sensible – and economically efficient – principle of good tax policy that stretches back even to Adam Smith (Winters, 2023).

The CBAM's purpose is to eliminate 'carbon leakage' whereby domestic production is displaced by production from jurisdictions that have no (fewer) restrictions on emissions – European Commission (2023, recital 12). The CBAM aims to offset this effect so far as sales in the EU are concerned. (If EU producers face ETS charges on their exports, they also face leakage in export markets, which requires a different solution – one which the EU has yet to specify fully). If emissions lead to charges on imports into the EU, there is an incentive for exporters to reduce emissions, so the CBAM is also "expected to effectively support the reduction of greenhouse gas emissions in third countries" (recital 14), a second contribution to the EU's objective of reducing global warming.

The CBAM is an adjunct to the ETS, and indeed, without an ETS, charging imports for their emissions amounts to little more than protectionism and would certainly fall foul of the World Trade Organization's rules.

This paper comments not on the CBAM per se, which we support, but on one particular aspect of its design, arguing that a simple modification would enhance its ability to reduce global greenhouse gas emissions. In particular, it would avoid a possible perversity of the current system whereby an improvement in emissions efficiency in the EU (or UK) could lead to an increase in global emissions.

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Both the EU and UK ETSs are cap-and-trade systems in which the authorities declare a total acceptable emissions level – based on trade-offs between slowing climate change and the cost of doing so in terms of foregone consumption (broadly interpreted). They then issue emission permits into a market which producers bid for and which also allows reselling between agents)[2] Having everyone bid in the same market ensures that every producer faces the same cost of emissions and hence the same incentives to abate emissions; this, in turn, ensures that abatement is achieved in the least-cost manner. This equality of cost across agents is the first-order condition for efficiency in the abatement market.[3]

The EU CBAM then adds another, separate, market in which importers buy CBAM permits from the authorities at the price determined by the domestic market for ETS permits.[4] In the EU the price will be updated every week and importers can buy as many permits as they wish at this price. At the end of each quarter, importers must hold permits covering at least 50% of the emissions associated with their imports up to that point in the reporting year.[5] This timing differs from the domestic market, in which the price can vary by the minute, but producers do not have to match permits and emissions even roughly through the year. The required amounts for the 50% will be calculated according to benchmark values, but if importers end the year with excess permits because their imports emit less than the benchmark amount, the authorities will buy the permits back at cost (up to a fairly generous limit). To a first approximation, this arrangement ensures that importers and domestic producers face the same price for emission permits.

The practicalities of the CBAM have attracted some discussion in the European Parliament, which plumped for the mechanism just described, terming it a 'notional ETS' – see Garicano's summary (2021, p. 9-10). We review the arguments for this preference below, but first, we address a feature that has so far received no attention. The proposed approach is not the only one to generate the same price for emissions at home and in imports; this would also be achieved if importers and domestic producers bought their permits in the same market. However, the two approaches have different implications in other dimensions, and we argue that the combined market is preferable in terms of reducing global emissions.

Before exploring this, we note that the UK intends to use a slightly different structure from the EU for its CBAM. Rather than sell certificates to importers, it has decided, *inter alia*, to levy a charge on imports at the border set by reference to the mean UK ETS price over the previous quarter. That is, there is no scope for arbitrage through time and the price is less flexible than the EU's, but the fundamental issue from our point of view is that it mimics the EU model of having separate 'markets' for carbon permits in the ETS and the CBAM, with quantities in the latter being completely unlimited. Importers play no role in the determination of the emissions permit price for imports,

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[2] The ETS legislation refers to 'allowances' and the EU CBAM legislation to 'certificates'. We use the term 'permits' to encompass both.

[3] There is one large caveat to the description in this paragraph. At present, to alleviate carbon leakage, the authorities issue free allowances of emissions permits to large emitters who are exposed to international trade. This removes some of the pressure, even if not the incentive, to abate emissions (firms can sell the free allowances on). The purpose of the CBAM is to replace the free allowances; in the EU the CBAM will be phased in at the same rate as the free allowances are phased out. The UK is currently planning to maintain some free allowances, but the issue still seems to remain somewhat open.

[4] It is the EU importer who is responsible for purchasing and surrendering the permits.

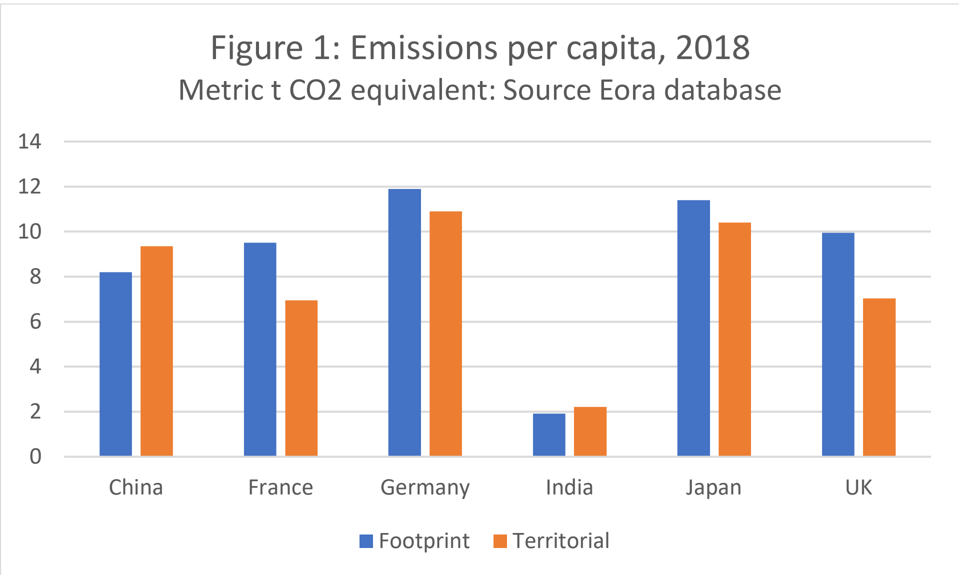
[5] The 50% figure comes from the so-called CBAM Omnibus Regulation of 2025, which has currently not quite completed its legislative journey – European Commission (2025). The previous figure was 80%.

merely accepting the domestic price and being able to 'buy' as many permits as they wish at that price. We describe the UK's (current) position in a little more detail in the Appendix.

A combined market for ETS and CBAM permits would see both importers and domestic producers competing over the same perfectly inelastic supply of permits (the cap). The authorities determine the cap on scientific grounds, but the price at which the market clears would provide information about the private value created by emitting and hence the private opportunity cost of abatement. A comparison with the authorities' estimates of the social cost of emissions allows an informed trade-off between climate and other economic objectives. If, on the other hand, there are separate markets as planned, domestic producers face a perfectly inelastic supply (the domestic ETS cap) while, given the price at any one time, the supply of CBAM permits is perfectly elastic. The domestic price of permits reflects EU/UK producers' abatement costs but not the cost of abating the emission-content of imports. The price of emissions is determined by a subset of players in the market for goods and imposed on the others. Thus, it gives only a partial estimate of the trade-off that EU consumers would make between climate and other objectives. An extreme parallel would be whether one would let the price of milk be determined by purchases only by people who are lactose-intolerant and then impose this price on everybody else.

The addition of the CBAM essentially converts the ETS from being a production-based policy to a consumption-based one (in the terms used in the Value-Added Tax literature, from an origin to a destination principle): the ETS charges producers (who implicitly pass the cost onto consumers) and the CBAM charges the other source of consumption – imports. For Europe and especially for the UK, this is an important extension. Figure 1 shows the territorial emissions per head (i.e. those used in domestic production) and the footprint emissions per head (i.e. related to final demand) for a selection of countries. The difference between the two is 'imports' of emissions and it is clearly large in Europe and particularly for the UK. In a different comparison for 2020, DEFRA (2023) estimates that emissions embedded in English imports of goods and services are 46% greater than emissions created in England to produce goods and services consumed by English residents. Clearly dealing with emissions in imports is a priority.

Figure 1: Emissions per capita, 2018



Under the current model, the authorities cap production emissions in their territories but let consumption emissions settle where they will. If, however, both producers and importers competed for the same cap, the authorities could directly determine the level of emissions for consumption by their residents. If one had full information, the two approaches could be engineered to generate an identical outcome, but that is a very high informational demand and the two approaches would still have different responses to any unforeseen shocks and, as a corollary, when there is uncertainty.[6]

If one accepts the argument that it would be better to have a single market for emission permits in which both domestic producers and importers participate, one might ask why, in that case, was the current system set up as it was. We would speculate that the current model is a product of a particular sequence of events. Emissions were originally seen as a production issue and policy and international negotiations focused on national targets to limit them. A natural instrument for limiting national territorial emissions was a domestic cap-and-trade system, which the EU introduced from 2005 – its Emissions Trading Scheme. As concerns about competitiveness and carbon leakage emerged, and having toyed with free allowances, the EU decided on charging imports at the same rate domestic producers and the CBAM was born. To our (imperfect knowledge) there was no serious talk of adding importers to the ETS market, perhaps because it was quite new and still going through its own teething troubles. However, Garicano (2021), minuting European Parliament proceedings, records combining the two markets as a possible step after the current model has become well established.

The rest of this paper comprises a simple diagrammatic exposition of the basic idea, a simple (but fuller) general equilibrium model to show the outcome in more general circumstances, some plausible simulations based on the iron and steel sector which suggest the superiority of our alternative and some brief concluding, practical, comments.

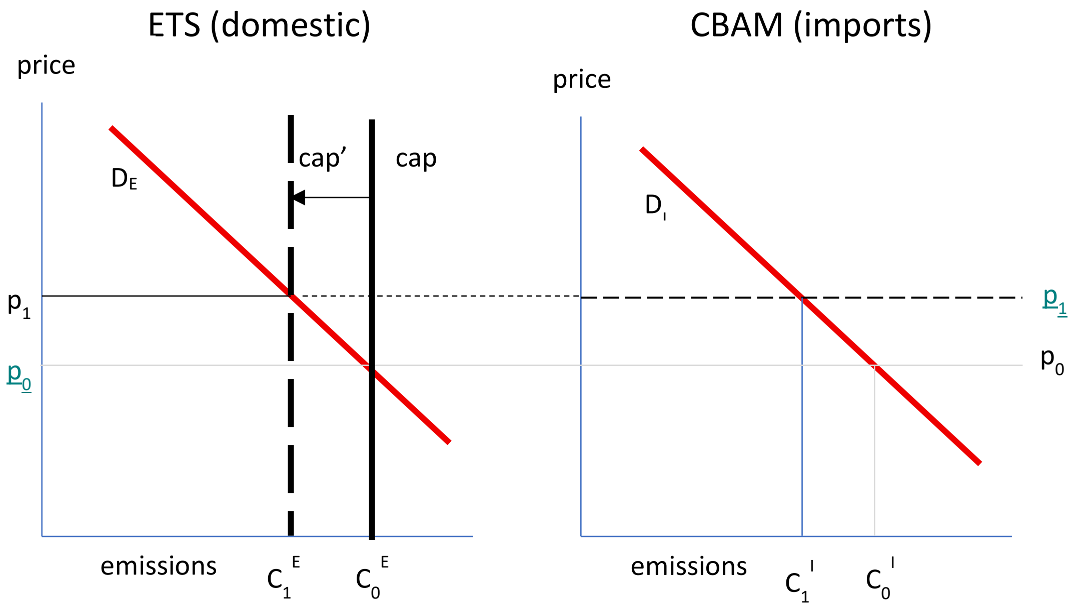
The paper examines the behaviour of the current and proposed CBAM designs once they are established, not the consequences of switching between systems nor the effects of introducing either from scratch.

1 The simplest model

Figure 2 shows how the ETS and CBAM permit markets for emissions of greenhouse gases are linked in the EU-style proposal, ignoring all the complications about free allowances, the timing of purchases, etc. The domestic demand for emissions permits is given by the red line D_E (demand is responsive to price) and the cap on permits by the solid black vertical line labelled 'cap' (unresponsive to price), which fixes emissions at C_0^E. The price of permits is determined in this market as p_0 and is then transferred to the CBAM permit market (we assume, perfectly). Given the demand for emissions among potential producers of imports (D_I), demand for emissions settles at C_0^I. In this illustration, the curves refer to total demand for emission permits and behind them are myriad decisions by firms about technologies, substitution between inputs, sales allocation between EU and other markets and the product mix within domestic output and imports.

[6] The idea is similar to that found in the analysis of the equivalence of tariffs and quotas in trade theory (Bhagwati 1965, and Fishelson and Flatters 1975).

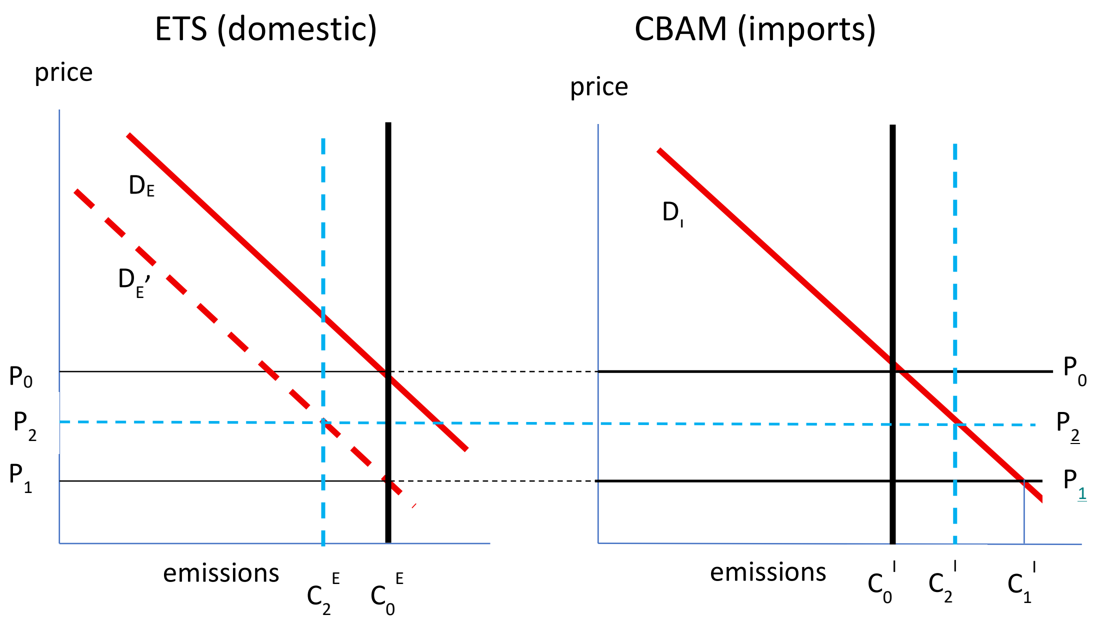
Figure 2: Emissions markets for UK domestic and imported CBAM sectors



We then ask what happens when the authorities reduce the emissions cap within the ETS to cap' – shown by the broken black vertical line. The story – exactly as one would wish – is that as the cap tightens, the price of ETS permits rises and as this is transferred to the CBAM market, emissions use in imports declines as well. In this figure, the two reductions happen to look roughly the same, but there is no guarantee that this is the case because the demand for emissions for imports could be larger or smaller than the domestic demand and/or more or less elastic. However, as Garicano (2021) notes, the cost of emissions is the same in the two markets – there is no discrimination.

Now consider Figure 3 where we assume that, again as desired, domestic industry is encouraged by the ETS to innovate such that the same output can be produced with fewer emissions. That implies that at any given permit price the demand for emissions is reduced – it shifts from D_E to D_E' in the left-hand panel. The level of emissions does not decline because the cap is fixed, so the permit price has to fall to p_1 to clear the market. When the new price is transferred to the market for imports, emissions increase to C_1^I and the technical progress has resulted in carbon leakage and increased emissions use to serve the EU market! In this case, transferring information by price alone fails the simple climate change test. To prevent this, the authority would have to reduce its ETS cap corresponding to the degree of technical progress to return the domestic emissions price to the original level, but that would vitiate the main attraction of the cap-and-trade system, that overall emissions levels are determined by climate policy. Note that none of this depends on the relative emissions-efficiency of the EU and foreign producers.

Figure 3: Improved energy efficiency with combined market for the ETS and CBAM permits



The example in the previous paragraph is a specific one, and it is possible that when technical progress occurs in the EU, it also occurs abroad or that it encourages some sectors/activities to relocate back to the EU. Both of these cases would imply that demand for emissions for imports declines along with domestic demand, and hence would reduce the leakage relative to that described. However, equally if more-emitting sectors relocated abroad from the EU, demand for emissions for domestic and imported production would move in opposite directions. The multitude of possible shocks and the constant flux in product mixes and technical progress, suggests that keeping the ETS cap adjusted in precisely the right way is next to impossible. But fortunately, there is an alternative that solves the problem automatically.

This involves a different CBAM design in which the markets for ETS permits and CBAM permits are combined. This is also explored in Figure 3. This would impose a cap on the emissions associated with *consumption* in the EU/UK rather than in *production*, and so be a major conceptual difference from the current EU CBAM, but one which is more coherent with the long-term objective of net-zero. There would be one cap for all goods consumed in the EU, so that any change in the call made on it by domestic producers would automatically be matched by an equal and opposite change in the call made by producers of imports.

In Figure 3 we assume that a joint cap is set at the level of emissions in the original equilibrium, namely ($C_0^E + C_0^I$) from Figure 2, replicated in Figure 3 by solid black vertical lines. The new equilibrium in which the EU required fewer emissions for a given output would be as shown by the blue broken lines and the subscript 2 in the Figure – that is by emissions of C_2^E and C_2^I and permit price p_2. It would come about by EU producers reducing their demand for emissions permits and producers of imports taking up the slack so that the overall level of emissions for the EU market was unchanged – viz. ($C_2^E + C_2^I$) = ($C_0^E + C_0^I$) – with the price of permits reflecting the two demand structures and the overall cap. With the combined market, there is still some leakage – emissions abroad still increase – but there is no increase in emissions due to the EU absorption of goods.

We have treated the technical progress as manna from heaven in this section, but of course it actually arises from firms' decisions to innovate. The combined market generates a smaller decline in the price of domestic emissions than does the CBAM, and this might be thought to reduce the incentive to innovate. Indeed, if one agent controlled innovation, they would presumably internalise this effect and cut innovation back.[7] However, in actuality many firms innovate (around 1,000 are part of the UK ETS and over 10,000 in the EU) and presumably they ignore the effect of their own innovation on the price of emission permits.

Further omissions in the diagrams are that we have ignored any spillover from the EU market to the rest of the world and any connections between the demands for domestic and imported goods in the EU. It is difficult to represent these in graphical case, but the theoretical model to which we now turn takes the latter into account.

2 A more formal model

The policy experiment we are examining in this section assumes that the EU has an Emissions Trading Scheme (ETS) which charges producers the emissions that they make via a cap-and-trade system. We then assume that it treats the problem of carbon leakage in the home market by having a Carbon Border Adjustment Mechanism (CBAM) that levies the same charge on emissions embodied in imports. The comparison is between two designs for the CBAM: one, which we label separate markets (SM), follows EU practice (effectively replicated by the UK) of taking the price of permits in the domestic cap and trade market periodically and selling permits to importers at that price over the following period. The alternative, which we term a Combined Market (CM), requires both domestic producers and importers to purchase permits in the same market – and hence at the same price. As laid out in the heuristic analysis above, we argue that the latter allows a more precise trade-off between slowing global warming and other economic objectives and offers policymakers more control for over the quantity of emissions generated by the EU. We are examining the different behaviour of these two systems once they are established, not asking about the consequences of switching from one to the other or the effects of introducing either system from scratch.

There are two countries, home and foreign, that can differ in size. There is an emitting good which is differentiated by origin, and consumers wish to consume both the domestic and foreign varieties. The production of these products uses labour and energy and hence emissions. Then there is a non-emitting good which is separable in utility from the emitting product, is freely traded internationally and produced in both countries using only labour, although potentially with different productivities. We can use it as numeraire as in Fullerton and Metcalf (2001) and this fixes the wage in each country. This allows us to rule out income effects and therefore focus only on the price of emissions.

The first-tier utility decisions between the emitting and non-emitting goods are Cobb-Douglas.[8] We assume perfect competition (including in the labour market), profit maximising behaviour and no uncertainty, but make no assumptions about the production functions of goods or the second-tier utility functions aggregating home and foreign emitting goods. The production functions include efficiency terms for labour, energy and emissions, and for total factor productivity. The effective

[7] The combined market also hands a smaller unrequited benefit to foreign competitors than does the separate markets model which conceivably might also affect innovation incentives.
[8] The utility functions also include terms in global emissions and revenue from permit sales, but we do not need to consider them in the exercise described here.

price of energy is the world price (assumed fixed) plus the cost of permits, and for international trade, we add iceberg transport costs.

There are no assumptions for the production functions nor the second-tier utility functions aggregating home and foreign emitting goods. This ensures that the general equilibrium responses are flexible so that we can see what kind of parameter restrictions (mainly on elasticities) are needed to drive results in one or another direction.

It has been unclear for some time whether the EU will rebate the cost of ETS permits to EU producers who export, the Commission insisting that it will not in the face of considerable industrial and political pressure to do so in order to maintain EU export competitiveness – e.g., Garicano (2021). It finally relented in a Press Statement on 3rd July 2025, with details promised by the end of the year – European Commission (2025b). With an export rebate, the ETS+CBAM becomes a charge on home consumption but not on exports to foreign. If, alternatively, there is no rebate, as the EU originally planned and the UK still plans, the ETS caps total emissions in home production, and home's emission costs apply equally to domestic sales and exports. We model both alternatives. Thus, while emissions in home's domestic sales are always subject to a cap, those in home's exports and foreign's exports to home may or may not be. Under SM emissions in foreign's exports face a charge but are not covered by the cap, whereas under CM they are included in a cap. (The possible forms for the rebate are discussed below.)

2.1 Production

The production of the non-emitting good X involves only labour and the production function is $X_i = L_i^X / \varphi_i^X$, where φ_i^X is labour productivity of country *i* in the production of X. This good is homogeneous and freely traded internationally and produced in both countries. This ensures that the price is common across countries and we use it as numeraire $p^X = 1$. The wage in each country is $w_i = p^X \varphi_i^X = \varphi_i^X$. It depends on the labour productivity, but we assume that this is fixed over the time horizon we are dealing with.

The production function of the emitting good q is $q_i = A_i f_i(L_i, e_i, A_i^e)$ which combines labour L_i and energy e_i , together with energy efficiency (units of energy input to produce one unit of output) A_i^e, and it is scaled by total factor productivity A_i. Without making assumptions on the form of the production function f_i , assume that cost minimization yields the demands for inputs as a function of total output, the price of inputs and (separably) TFP. Then we have:

$$\begin{cases} e_i^d = e_i^d(q_i, p_i^e, A_i^e) A_i^{-1} \\ L_i^d = L_i^d(q_i, p_i^e, A_i^e) A_i^{-1} \end{cases} \quad (1)$$

Where p^e is the price of energy defined as:

$$p_i^e = p^C + A_i^E p^E \quad (2)$$

where p^C is the price of a unit of fuel, A_i^E is the emissions associated with one energy unit, which can be seen as a measure of emission efficiency, and p^E is the cost of the permit for one unit of emissions, i.e. the ETS price. In the numerical application to the steel sector, p^C will be the world price per ton of metallurgic coal used in the production of steel. A_i^E will measure how many tons of carbon dioxide are released from one ton of coal and p^E the permit price for one ton of carbon dioxide.

While the shocks we examine imply changes in the global demand for energy – albeit relatively small ones – we assume that the supply curve of energy is horizontal. Hence, we treat the world price of coal p^C as fixed, and when looking at the model in terms of differences we will keep track only p^E.

Totally differentiate the demand for energy to get:

$$\hat{e}_i^d = \epsilon_i^d \hat{q}_i + \epsilon_i^{p^e} \hat{p}_i^e + \epsilon_i^{A^e} \hat{A}_i^e - \hat{A}_i \tag{3}$$

where the ϵs are the elasticities of the demand for emissions, and we have $\epsilon_i^{p^e} < 0$ and $\epsilon_i^{A^e} = \epsilon_i^{p^e} + 1$. If $\left|\epsilon_i^{p^e}\right| < 1$, the elasticity of energy demand with respect to energy efficiency is positive, so that an increase in energy efficiency ($\hat{A}_i^e < 0$) results in a decrease in energy demand, while if $\left|\epsilon_i^{p^e}\right| > 1$ an improvement in efficiency results in an increased energy demand. As we explain below, the former appears to be the more normal case.

The marginal cost will be a function of the input prices p^e and $w_i = \varphi_i^X$. Because labour productivity is constant, in differences we need consider only the change in p^e. Moreover, given a fixed world price of coal, the change in the overall price of energy depends on the emission permit price and on emission efficiency:

$$\hat{p}_i^e = \frac{A_i^E p^E}{p_i^e}\left(\hat{A}_i^E + \hat{p}^E\right) \tag{4}$$

Where the term $A_i^E p^E / p_i^e$ represents the share of emissions cost in total energy cost.

In perfect competition, the price equals the marginal cost, so we have an expression for the output price of the type $p_i = p_i(p_i^e, A_i^e) A_i^{-1}$. Given our assumption of a fixed world price of energy input p^C, by totally differentiating the price function we get:

$$\hat{p}_i = \sigma_i \frac{A_i^E p^E}{p_i^e}\left(\hat{A}_i^E + \hat{p}^E\right) + \sigma_i \hat{A}_i^e - \hat{A}_i \tag{5}$$

where σ_i is the elasticity of output price with respect to the total energy price. For international trade we add iceberg transport costs $\tau \geq 1$ such:

$$\hat{p}_{ij} = \sigma_i \frac{A_i^E p^E}{p_i^e}\left(\hat{A}_i^E + \hat{p}^E\right) + \sigma_i \hat{A}_i^e - \hat{A}_i + \hat{\tau}_{ij} \tag{6}$$

where p_{ij} is the price of the product produced *i* and sold in *j*.

2.2 Consumption

The representative consumer at home (H) has a utility function given by:

$$U_i = u\left[\left(X_i^{1-\alpha} Q_i^{\alpha}\right), G_i, g(E)\right] \tag{7}$$

The first term is a Cobb-Douglas index over the consumption of the non-emitting good X and the emitting product $Q = Q(q_H, q_F)$ that combines the home q_H and foreign q_F varieties. G_i is a nonrival public good provided by the government of *i* paid for by the entirety of the revenues raised from the sales of emission permits so that revenues are fully redistributed to consumers. Hence, we have $G_i = p^E E^S$ where E^S is the supply of emission permits measured in tons of carbon dioxide. In the foreign economy revenues from permit sales are zero. Emissions have a negative effect on utility via the nonrival term $g(E)$, which captures the effect of global emissions E on consumers' utility, and we have $g' < 0$. In choosing the optimal consumption level, the consumer takes the provision of the public good and the negative externality of global emissions as given. Hence, the first-tier utility maximization is done over X and Q and it yields constant expenditure shares.

The change in total consumption is given by:

$$\hat{Q}_i = \phi_{ii} \hat{q}_{ii} + \phi_{ji} \hat{q}_{ji} \tag{8}$$

with ϕ_{ii} being the consumption share of q_i and ϕ_{ji} the share of q_j in country *i*.

In general terms we can define the Marshallian demand for q_{ii} as a function of income Y_i, the own price p_{ii} and the foreign price p_{ij}: $q_{ii} = D(Y_i, p_{ii}, p_{ij})$.[9] Totally differentiate demands to get the demand for home products in the home market:

$$\hat{q}_{HH} = \eta_{HH}^{p_H}\hat{p}_H + \eta_{HH}^{p_F}(\hat{p}_F + \hat{\tau}) \tag{9}$$

and demand for home products in the foreign market:

$$\hat{q}_{HF} = \eta_{HF}^{p_F}\hat{p}_F + \eta_{HF}^{p_H}(\hat{p}_H + \hat{\tau}) \tag{10}$$

where the ηs are the own- and cross-price elasticities of demand (notation: $\eta_{HH}^{p_H}$ is the elasticity of demand for product originating in H sold in market H with respect to its own-price, while $\eta_{HF}^{p_F}$ is the elasticity of demand for H in market F with respect to the price of *F* – the cross-price elasticity). The fixity of wages and the labour force mean that nominal income is constant and any changes in real income or the trade balance deriving from price changes are entirely absorbed by changes in consumption and/or trade of the homogeneous good. This implies that in this exercise the demand for the differentiated good has no income effect.

Total output of country H is $q_H = q_{HH} + q_{HF}$ so the change is:

$$\hat{q}_H = \theta_H\hat{q}_{HH} + (1 - \theta_H)\hat{q}_{HF} \tag{11}$$

where θ_H is the share of H's output sold in the domestic market.

2.3 Two CBAM designs, one framework

The two CBAM designs considered here, namely Separate Markets (SM) and Combined Markets (CM), differ in terms of direct control over the emissions. SM, including exports from H, (i.e., with no export rebate) directly controls emissions for all production in H. Foreign emissions of output destined to the Home market adjust only via the price mechanism. In the CM policy (with exports), there is direct control over the sum of H's emissions and F's emissions for exports to H. Under both designs, foreign emissions for foreign domestic sales adjust only via the competition effects of H in F's domestic market.

The two variables in which we are interested for climate analysis are the change in the price of emissions – the permit price - and the change in global emissions following a change in the exogenous variables. A change in global emissions can be expressed as:

$$\hat{E} = s_{HH}\hat{E}_{HH} + s_{HF}\hat{E}_{HF} + s_{FF}\hat{E}_{FF} + s_{FH}\hat{E}_{FH} \tag{12}$$

where $s_{ij} = E_{ij}/E$ represents the starting period share of emissions produced by producers in i associated with products sold in market *j*. Emissions are a by-product of energy consumption; for each unit of energy consumed, producer *i* emits A_i^E units of emissions: $E_{ij} = A_i^E e_{ij}$.

The two designs put different constraints on (12). Given a supply of emission permits E^S, the policies will cover different parts of the global market.

Before detailing these, however, we need to specify more clearly the form of any export rebate.[10] The term 'rebate' suggests that exports would be included in the domestic cap, but that the cost of them would be refunded at a later date. This implies that for any emissions cap covering home

[9] We know that the uncompensated Marshallian price elasticity of demand is given by $\eta_{ij} = -\delta_{ij} + \frac{\partial \ln s_{ij}}{\partial \ln p_{ij}}$, with $\delta_{i=j} = 1$ and $\delta_{i\neq j} = 0$.

[10] Its form has not - to our knowledge – been discussed previously, which is perhaps not surprising given the official rejection of a rebate.

production as a whole, only part of that production would have incentives to adjust, because the change in export prices would exclude terms related to permits, so that equation (6) would become

$$\hat{p}_{HF} = \sigma_H \hat{A}_H^e - \hat{A}_H + \hat{\tau}_{HF}$$

Because exporters bidding for permits were completely indifferent to the price they paid, the burden of adjustment would fall entirely on emissions for domestic sales. If permit numbers for home production were reduced, an *a*% reduction in total emissions would need a reduction of *(a/r)*% in emissions for domestic sales, where *r* is the share of total emissions emanating from domestic sales. The current net-zero policy calls for the gradual tightening of total domestic permit numbers, so the distortion between home sales and exports would eventually become very large.

Paying a rebate would also pose a number of practical problems such as establishing procedures for paying it, avoiding claims that these constituted export subsidies, and fixing the price for the rebated permits (which could be any of the market annual average, the firm's annual average permit price, the prices at time of export etc.). The alternative, and much simpler, approach would be just to exempt exports from having to surrender permits. This is the form of the rebate that we model.

A complication faced by either form of rebate would be the treatment of exports undertaken by distributors rather than the producers themselves.[11] Any payment or exclusion would have to be made against evidence of export of a defined set of trade headings defined as any direct exports by the producers plus certificates for exports made by distributors. This is an issue that needs a solution: UK data suggest that between a third and a half of UK exports of iron and steel and articles of iron and steel occur through distributors – CITP internal report.

On 3rd July 2025, the Commission announced that it would be rebating ETS costs on exports, but without any details (European Commission, 2025b), although Hancock (2025) suggests it will take the form of a cash repayment. Until we have details, however, we will model the rebate as an exclusion.

Returning to the different constraints on (12), under SM with an export rebate, the emissions target is sales in *H* by *H* , so we will set $\hat{E}_{HH} = \hat{E}^s$, leaving the other emission choices free to adjust. Under SM with no rebate, policy controls both *H*'s domestic sales and exports, which implies that $s_{HH}^H \hat{E}_{HH} + s_{HF}^H \hat{E}_{HF} = \hat{E}^s$, and if we have CM with no rebate, we impose $s_{HH}^H \hat{E}_{HH} + s_{HF}^H \hat{E}_{HF} + s_{FH}^H \hat{E}_{FH} = \hat{E}^s$. The quantities of carbon emissions capped by the policy differ across the scenarios, but we maintain the notation E^s to indicate the supply of permits across all policy settings.

The next part that we need to derive is the change in the price of emissions given a change in the exogenous variables. Because we hold constant the price of energy and the wage (with the choice of the numeraire), the change in the price of emissions $\hat{p}^E$ is what will determine the changes in consumption of the carbon emitting good *Q*, emissions demand and government revenues.

To find the change in the permit price, we start from the following system of linear equations:

[11] We presume that this would not include exports of goods on which any further processing had been conducted – only those in the same form as when they left the producers.

$$\begin{cases} \hat{e}_{ij} = \epsilon_i^q \hat{q}_{ij} + \epsilon_i^{p^e} \frac{A_i^E p^E}{p_i^e} \left(\hat{A}_i^E + \hat{p}^E\right) + \epsilon_i^{A^e} \hat{A}_i^e - \hat{A}_i \\ \hat{q}_i = \theta_i \hat{q}_{ii} + (1-\theta_i)\hat{q}_{ij} \\ \hat{q}_{ij} = \eta_{ij}^{p_i}\left(\hat{p}_i + \hat{\tau}_{ij}\right) + \eta_{ij}^{p_j}(\hat{p}_j + \hat{\tau}_{jj}) \\ \hat{p}_{ij} = \sigma_i \frac{A_i^E p^E}{p_i^e}\left(\hat{A}_i^E + \hat{p}^E\right) + \sigma_i \hat{A}_i^e - \hat{A}_i + \hat{\tau}_{ij} \end{cases}$$

together with the permit market equilibrium condition:

$$\widehat{Permits} = \hat{E}^s \tag{13}$$

where $\widehat{Permits}$ is the demand for emissions permits covered by the cap-and-trade system. The demand for permits will change depending on the policy scenario.

In the Appendix, we show how the change in the price of emissions can be derived as a function of changes in all exogenous variables. Here we present the change in the price of emissions given a change in the cap ($\hat{E}^s$), *H*'s emission efficiency $\hat{A}_H^E$ and *H*'s energy efficiency $\hat{A}_H^e$:

$$\hat{p}^E = \frac{\widehat{E_H^s}}{\varepsilon} - \frac{\tilde{s}_H\left[1 + \left(1 - \mathbb{1}(EX)(1-\theta_H)\right)\epsilon_H^q \eta_{HH}^{p_H} \sigma_H \frac{A_H^E p^E}{p_H^e} + \mathbb{1}(EX)(1-\theta_H)\epsilon_H^q \eta_{HF}^{p_H}\sigma_H \frac{A_H^E p^E}{p_H^e} + \epsilon_H^{p^E}\right] + (1-\tilde{s}_H)\eta_{FH}^{p^H}\sigma_H \frac{A_H^E p^E}{p_H^e}}{\varepsilon}\hat{A}_H^E - \frac{\tilde{s}_H\left[\left(1 - \mathbb{1}(EX)(1-\theta_H)\right)\epsilon_H^q \eta_{HH}^{p_H}\sigma_H + \mathbb{1}(EX)(1-\theta_H)\epsilon_H^q \eta_{HF}^{p_H}\sigma_H + \epsilon_H^{A^e}\right] + (1-\tilde{s}_H)\eta_{FH}^{p^H}\sigma_H}{\varepsilon}\hat{A}_H^e \tag{14}$$

Where we express $\epsilon_i^{p^E} = \epsilon_i^{p^e}(\frac{A_i^E p^E}{p_i^e})$ for compactness and we define $\mathbb{1}(EX)$ as an indicator that equals one if the policy covers exports – the case with no export rebate – and zero otherwise – i.e., with an export rebate. By defining $\tilde{s}_H$ appropriately, expression (14) encompasses all four policy scenarios that we consider: Separate or Combined Markets, with or without export rebate. In particular, we define:

$$\tilde{s}_H = \frac{E_{HH} + \mathbb{1}(\text{EX})E_{HF}}{E_{HH} + \mathbb{1}(\text{EX})E_{HF} + \mathbb{1}(\text{policy=CM})E_{FH}} \tag{15}$$

Where $\mathbb{1}(\text{policy=CM})$ is an indicator that equals one if the policy is Combined Markets and zero for Separate Markets. The denominator in (15) is total emissions covered by the policy. Hence, in case of Separate Markets $\tilde{s}_H = 1$, while for Combined Markets $\tilde{s}_H \leq 1$ and depends on the initial levels of emissions. The first term on the RHS of equation (14) describes the reaction of the price of emissions to a change in the cap, the second to changes in emission efficiency of H, and the third to changes in the energy efficiency of H. Equation (14) is derived by setting changes in labour force size and trade costs to zero.

The effect of the two designs can be computed by tuning some of the parameters in equation (14). If we are interested in a policy that affects only the domestic sales of country H, but not its exports to F, we can set $\mathbb{1}(\text{EX}) = 0$. This implies that the change in the price of emissions depends only on *H*'s domestic sales, but not on how the foreign demand varies. Under SM only domestic production is covered by the emission cap. The adjustment in the price of emissions can be computed by setting $\tilde{s}_H = 1$ in (14).

For convenience we will use the term ε to capture the general equilibrium change in the demand for emissions accounting for the changes in the demand for emitting varieties. It is a function of several elasticities and is defined precisely in the Appendix. While the sign of ε is not restricted, we proceed by making the reasonable assumption that $\varepsilon < 0$ such that *ceteris paribus* an increase in the supply of emissions (that is, a relaxation in the cap) reduces the price of emissions, under both SM and CM. This assumption essentially says that in the demand for the carbon-emitting variety, the own price effect is larger than the indirect effect (price of substitute), which is a common feature of many demand systems. This means that a 10% increase in the own price has a larger (absolute) effect on demand than a 10% increase in the price of a substitute product. Finally, we will use $\varepsilon(\tilde{s}_H = 1)$ to indicate ε under the Separate Market case, in which the restriction $\tilde{s}_H = 1$ applies, while use only ε for the Combined Market case.

2.4 Exogenous shocks

2.4.1 Change in the CAP

Consider a change in the cap which becomes more stringent such that $\hat{E}^s < 0$. Under SM, the price of emissions changes according to:

$$\hat{p}^E = \frac{\widehat{E^s}}{\varepsilon(\tilde{s}_H = 1)} \tag{16}$$

Given the assumption that ε <0, this implies an increase in the price of emission permits $\hat{p}^E > 0$.

To compute the adjustment of global emissions we need to compute the changes in F's emissions, as *H*'s emissions change is equal to the change in the cap.

For F's exports to H the adjustment follows the adjustment of the price of emissions hence we have:

$$\hat{E}_{FH} = \frac{\epsilon_F^q \left(\eta_{FH}^{p_F} \sigma_F \frac{A_F^E p^E}{p_F^e} + \eta_{FH}^{p_H} \sigma_H \frac{A_H^E p^E}{p_H^e} \right) + \epsilon_F^{p^e} \frac{A_F^E p^E}{p_F^e}}{\varepsilon(\tilde{s}_H = 1)} \hat{E}^s < 0 \tag{17}$$

The first part in the numerator of (17) represents the adjustment due to changes in quantities of final product sold. The second term accounts for the price effect in the demand for energy and thus permits.

If H's exports are covered, then we also have an adjustment in F's 'domestic' emissions due to the declining competitiveness of H's products in F's market. This adjustment is:

$$\hat{E}_{FF} = \frac{\epsilon_F^q \eta_{FF}^{p_H} \sigma_H \frac{A_H^E p^E}{p_H^e}}{\varepsilon(\tilde{s}_H = 1)} \hat{E}^s > 0 \tag{18}$$

Given the increase in the cost of H's products due to the more stringent cap imposed, F's product gains market share at home (it does not pay for emissions there) and hence expands and increases emissions.

Under the Combined Markets (CM) scenario, the change in the price of emissions is given by:

$$\widehat{p^E} = \frac{\hat{E}^s}{\varepsilon} > 0 \tag{19}$$

the change in emissions related to F's exports to H is now covered by the policy. If the policy does not apply to H's exports, there is no change in the price of H's exports and hence no change in the quantities sold in market *F* and their associated emissions.

If, instead, exports are covered we have a change in H's export price. This affects the equilibrium quantities sold in market *F* and *F*'s emissions associated to its domestic sales change:

$$\hat{E}_{FF} = \frac{\epsilon_F^q \eta_{FF}^{p_H} \sigma_H \frac{A_H^E p^E}{p_H^e}}{\varepsilon} \hat{E}^s > 0 \tag{20}$$

Looking at global emissions, under the SM design without an export rebate, the change in global emissions is:

$$\hat{E} = (s_{HH} + s_{HF})\hat{E}^s + s_{FF} \frac{\epsilon_F^q \eta_{FF}^{p_H} \sigma_H}{\varepsilon(\tilde{s}_H = 1)} \frac{A_H^E p^E}{p_H^e} \hat{E}^s + s_{FH} \frac{\epsilon_F^q \left(\eta_{FH}^{p_F} \sigma_F \frac{A_F^E p^E}{p_F^e} + \eta_{FH}^{p_H} \sigma_H \frac{A_H^E p^E}{p_H^e}\right) + \epsilon_F^{p^e} \frac{A_F^E p^E}{p_F^e}}{\varepsilon(\tilde{s}_H = 1)} \hat{E}^s \tag{21}$$

While under CM we have:

$$\hat{E} = (s_{HH} + s_{HF} + s_{FH})\hat{E}^s + s_{FF} \frac{\epsilon_F^q \eta_{FF}^{p_H} \sigma_H}{\varepsilon} \frac{A_H^E p^E}{p_H^e} \hat{E}^s \tag{22}$$

2.4.2 Change in Home's emission efficiency

Consider now an improvement in the emissions efficiency of home $\hat{A}_H^E < 0$ while holding everything else constant. The change in the price of emission permits can be derived by setting $\hat{E}^s$ and $\hat{A}_H^e$ equal to zero in equation (14). With our assumption that $\varepsilon < 0$, an efficiency improvement at home decreases the price of emissions.

The changes in emissions sum to zero for the markets covered by the policy, as there is no change in the cap. For emissions related to sales in non-covered markers, we have to work out the effects on prices and quantities sold.

Separate markets with export rebate:

In this case, the only emissions capped are those related to *H*'s domestic sales. *F*'s emissions related to sales in market *H* change because they are affected by the change in the permit price, but they are free to adjust. *H's* exports to *F* do not pay for emission permits, hence there is no change in *H*'s export price p_{HF}. Consequently, there is no change in sales in market *F* ($\hat{q}_{HF} = 0$ and $\hat{q}_{FF} = 0$). At the same time, *H*'s exports emissions are reduced due to *H* becoming more emission efficient. Table 1 summarises the changes.

Table 1: Separate Markets with export rebate

a) Price changes			b) Quantity changes			c) Emission changes		
Seller	Buyer		Seller	Buyer		Seller	Buyer	
	Home	Foreign		Home	Foreign		Home	Foreign
Home	$\hat{p}_{HH}$	0	Home	$\hat{q}_{HH}$	0	Home	0	$\hat{A}_H^E$
Foreign	$\hat{p}_{FH}$	0	Foreign	$\hat{q}_{FH}$	0	Foreign	$\hat{E}_{FH}$	0

The global emission change is given by:

$$\hat{E} = s_{HF}\hat{A}_H^E + s_{FH}\hat{E}_{FH} \tag{23}$$

Where the first term refers to the emission efficiency change in *H*'s exports to *F*, while the second is related to *F*'s exports to *H*.

The change in *F's* exports is:

$$\hat{q}_{FH} = \eta_{FH}^{p_F}\sigma_F \frac{A_F^E p^E}{p_F^e}\hat{p}^E + \eta_{FH}^{p_H}\sigma_H \frac{A_H^E p^E}{p_H^e}\left(\hat{p}^E + \hat{A}_H^E\right) \tag{24}$$

$$\begin{aligned}\hat{E}_{FH} = \hat{e}_{FH} &= \epsilon_F^q \hat{q}_{FH} + \epsilon_F^{p^e} \frac{A_F^E p^E}{p_F^e}\hat{p}^E \\ &= \epsilon_F^q \left[\eta_{FH}^{p_F}\sigma_F \frac{A_F^E p^E}{p_F^e}\hat{p}^E + \eta_{FH}^{p_H}\sigma_H \frac{A_H^E p^E}{p_H^e}\left(\hat{p}^E + \hat{A}_H^E\right)\right] + \epsilon_F^{p^e} \frac{A_F^E p^E}{p_F^e}\hat{p}^E\end{aligned} \tag{25}$$

with $\hat{p}^E$ being calculated as described in (14).

Separate Markets without export rebate:

In this case, the cap also includes *H*'s exports. *F*'s emissions related to sales in market *H* change as before. *H*'s exports to *F* now pay for emission permits, hence *H* export price p_{HF} changes and therefore q_{HF}. This also induces a competition effect, leading to $\hat{q}_{FF} \neq 0$. Table 2 summarises the changes.

Table 2: Separate Markets without export rebate

a) Price changes			b) Quantity changes			c) Emission changes		
Seller	Buyer		Seller	Buyer		Seller	Buyer	
	Home	Foreign		Home	Foreign		Home	Foreign
Home	$\hat{p}_{HH}$	$\hat{p}_{HF}$	Home	$\hat{q}_{HH}$	$\hat{q}_{HF}$	Home	0*	0*
Foreign	$\hat{p}_{FH}$	0	Foreign	$\hat{q}_{FH}$	$\hat{q}_{FF}$	Foreign	$\hat{E}_{FH}$	$\hat{E}_{FF}$

Note: in the emission tables, a 0* indicates that the sum of all emissions changes for the markets labelled with 0* is equal to zero.

The global emission change is given by:

$$\hat{E} = s_{FH}\hat{E}_{FH} + s_{FF}\hat{E}_{FF} \tag{26}$$

The expression for the change in *F* exports is the same as above, while the change in *F*'s domestic sales is:

$$\hat{q}_{FF} = \eta_{FF}^{p_H}\sigma_H \frac{A_H^E p^E}{p_H^e}\left(\hat{p}^E + \hat{A}_H^E\right) \tag{27}$$

Hence the associated change in emissions is:

$$\hat{E}_{FF} = \hat{e}_{FF} = \epsilon_F^q \eta_{FF}^{p_H}\sigma_H \frac{A_H^E p^E}{p_H^e}\left(\hat{p}^E + \hat{A}_H^E\right) \tag{28}$$

Combined Markets with export rebate:

In this case, all emissions related to sales in *H* are capped. As for the Separate Markets with rebate, there is no change in *H*'s export price and quantities, hence no change in *F*'s domestic sales. The only change in emissions is related to *H*'s exports as it becomes more emission efficient:

$$\hat{E} = s_{HF}\hat{A}_H^E$$

Table 3 summarises the changes.

Table 3: Combined Markets with export rebate

a) Price changes			b) Quantity changes			c) Emission changes		
Seller	Buyer		Seller	Buyer		Seller	Buyer	
	Home	Foreign		Home	Foreign		Home	Foreign
Home	$\hat{p}_{HH}$	0	Home	$\hat{q}_{HH}$	0	Home	0*	$\hat{A}_H^E$
Foreign	$\hat{p}_{FH}$	0	Foreign	$\hat{q}_{FH}$	0	Foreign	0*	0

Note: in the emission tables, a 0* indicates that the changes of the sum of all emissions for the markets labelled with 0* are equal to zero.

Combined Markets without export rebate:

Under the CM design without an export rebate, the cap also includes *H*'s exports to *F*. These pay for emission permits, hence *H*'s export price and quantity change, and competition effects lead to $\hat{q}_{FF} \neq 0$. Table 4 summarises the changes. The only change in emissions is related to *F*'s domestic sales: $\hat{E} = s_{FF}\hat{E}_{FF}$

Table 4: Combined Markets without export rebate

a) Price changes			b) Quantity changes			c) Emission changes		
Seller	Buyer		Seller	Buyer		Seller	Buyer	
	Home	Foreign		Home	Foreign		Home	Foreign
Home	$\hat{p}_{HH}$	$\hat{p}_{HF}$	Home	$\hat{q}_{HH}$	$\hat{q}_{HF}$	Home	0*	0*
Foreign	$\hat{p}_{FH}$	0	Foreign	$\hat{q}_{FH}$	0	Foreign	0*	$\hat{E}_{FF}$

Note: in the emission tables, a 0* indicates that the changes of the sum of all emissions for the markets labelled with 0* are equal to zero.

2.4.3 Change in Home's energy efficiency

In this section we look at the scenario in which Home becomes more energy efficient ($\hat{A}_H^e < 0$). As we will see, a change in *energy* efficiency has different implications from those with of a change in *emissions* efficiency. With a change in emission efficiency, prices change only in markets covered by the emission policy – where emissions have a price. On the other hand, a change in energy efficiency will change the price of *H's* goods in both markets whether covered by the emissions policy or not.

In addition, the increase in energy efficiency generates a change in the price of emission permits. The change in the permit price given a change in the energy efficiency of *H* while keeping everything else constant is given by:

$$\hat{p}^E = -\frac{\tilde{s}_H\left[\left(1-\mathbb{1}(EX)(1-\theta_H)\right)\epsilon_H^q\eta_{HH}^{p_H}\sigma_H + \mathbb{1}(EX)(1-\theta_H)\epsilon_H^q\eta_{HF}^{p_H}\sigma_H + \epsilon_H^{A^e}\right] + (1-\tilde{s}_H)\eta_{FH}^{p^H}\sigma_H}{\varepsilon}\hat{A}_H^e$$

The term multiplied by $\tilde{s}_H$ measures the response of the permits demand for sales destined to the home market, while the term multiplied by $1 - \tilde{s}_H$ represents the change related to sales in the foreign market. Within the brackets, the first two terms are due to changes in demand for final output (which depends on whether an export rebate is present or not), while the final term $\epsilon_H^{A^e}$ accounts for the change in emission efficiency.

The effect of an energy efficiency change on the price of permits depends on the value of the parameters, but it is most likely negative – i.e., increased energy efficiency reduces demand for energy and hence permits, so the price of permits drops.

The price of *H*'s products changes both because of the energy efficiency gain and because of the emission permits change. In a market covered by the emissions policy we have:

$$\hat{p}_H = \sigma_H \left(\frac{A_H^E p^E}{p_H^e} \hat{p}^E + \hat{A}_i^e \right)$$

while in markets not covered the change is only $\sigma_H \hat{A}_i^e$. These price changes induce changes in quantities sold hence on the energy demand and emissions.

Table 5-Table 8 report the changes in prices, quantities and emissions under the four different policy designs.

Table 5: Separate Markets with export rebate

a) Price changes				b) Quantity changes				c) Emission changes		
Seller	Buyer			Seller	Buyer			Seller	Buyer	
	Home	Foreign			Home	Foreign			Home	Foreign
Home	$\hat{p}_{HH}(\hat{p}^E, \hat{A}_H^e)$	$\hat{p}_{HF}(\hat{A}_H^e)$		Home	$\hat{q}_{HH}$	$\hat{q}_{HF}$		Home	0	$\hat{E}_{HF}$
Foreign	$\hat{p}_{FH}(\hat{p}^E)$	0		Foreign	$\hat{q}_{FH}$	$\hat{q}_{FF}$		Foreign	$\hat{E}_{FH}$	$\hat{E}_{FF}$

Table 6: Separate Markets without export rebate

a) Price changes				b) Quantity changes				c) Emission changes		
Seller	Buyer			Seller	Buyer			Seller	Buyer	
	Home	Foreign			Home	Foreign			Home	Foreign
Home	$\hat{p}_{HH}(\hat{p}^E, \hat{A}_H^e)$	$\hat{p}_{HF}(\hat{p}^E, \hat{A}_H^e)$		Home	$\hat{q}_{HH}$	$\hat{q}_{HF}$		Home	0*	0*
Foreign	$\hat{p}_{FH}(\hat{p}^E)$	0		Foreign	$\hat{q}_{FH}$	$\hat{q}_{FF}$		Foreign	$\hat{E}_{FH}$	$\hat{E}_{FF}$

Table 7: Combined Markets with export rebate

a) Price changes				b) Quantity changes				c) Emission changes		
Seller	Buyer			Seller	Buyer			Seller	Buyer	
	Home	Foreign			Home	Foreign			Home	Foreign
Home	$\hat{p}_{HH}(\hat{p}^E, \hat{A}_H^e)$	$\hat{p}_{HF}(\hat{A}_H^e)$		Home	$\hat{q}_{HH}$	$\hat{q}_{HF}$		Home	0*	$\hat{E}_{HF}$
Foreign	$\hat{p}_{FH}(\hat{p}^E)$	0		Foreign	$\hat{q}_{FH}$	$\hat{q}_{FF}$		Foreign	0*	$\hat{E}_{FF}$

Table 8: Combined Markets without export rebate

a) Price changes				b) Quantity changes				c) Emission changes		
Seller	Buyer			Seller	Buyer			Seller	Buyer	
	Home	Foreign			Home	Foreign			Home	Foreign
Home	$\hat{p}_{HH}(\hat{p}^E, \hat{A}_H^e)$	$\hat{p}_{HF}(\hat{p}^E, \hat{A}_H^e)$		Home	$\hat{q}_{HH}$	$\hat{q}_{HF}$		Home	0*	0*
Foreign	$\hat{p}_{FH}(\hat{p}^E)$	0		Foreign	$\hat{q}_{FH}$	$\hat{q}_{FF}$		Foreign	0*	$\hat{E}_{FF}$

3 Numerical exercise

Theoretically, it is ambiguous whether home's emissions- or energy-efficiency improvement increases global emissions, so to gauge whether this is a material concern we now simulate the model. We consider the EU27 as the home country and the rest of the world (RoW) as the foreign economy. We base the behavioural parameters on the iron and steel sector, which is the main sector currently affected by the CBAM. The values of parameters used in the simulation are summarised in Table 9 below along with sources and in three cases alternative values for sensitivity testing. For lack of information, some assumptions need to be made.

We simulate four CBAM designs – separate markets (SM) and a combined market (CM) for permits, each with and without an export rebate – and ask what would happen to emission prices and total world emissions given an improvement in the emission or energy efficiency of home producers. The simulations are based on equation (14) for the change in the emission price, and equations (23)-(28) for the change in global emissions. For each design we do 18 simulations using all combinations of the three parameters for which we give alternative values in Table 9. We do not consider dynamics, but there is no reason to think they will differ between the two CBAM-designs.

We assume a unitary elasticity of energy demand with respect to output ϵ_i^q. For the elasticity of energy demand with respect to the price of energy $\epsilon_i^{p^e}$, we take the value of -0.75 from Wang et al. (2021), who use data from different Chinese sectors over 1999-2015 to estimate an energy consumption function. For the 'Non-metal & metal sectors' the average elasticity is -0.778. For ferrous metals, the elasticity varies over time between -0.75 and -1.0, while for non-ferrous metals the elasticity is -0.5 and stable over time. We start with the central value of -0.75 and perform sensitivity analysis by adding ±0.25 to this value. We set the elasticity of energy demand with respect to energy efficiency equal to one plus the price elasticity $\epsilon_i^{p^e}$, so it also varies by ±0.25 in the sensitivity tests.

The literature on the so-called rebound effect in iron and steel – the extent to which improvements in energy efficiency lead to reductions in energy use – also offers insight into the elasticity of energy demand, although it typically combines the substitution between energy and other factors of production, which is the parameter we require, with an output effect induced by the stimulus to demand arising from output price reductions that improved energy efficiency permits. These papers tend to suggest substitution effects somewhat smaller (absolutely) than Wang et al.'s, which is why we have used the latter's smaller estimate as our central case. More importantly, the papers based on data after around 2000 suggest that the rebound effect is less than 100% - e.g. Amjadi et al (2018) and Wang et al (2018). That is, while the rebound means that the decline in energy use is less than the improvement in energy efficiency, the latter never leads to higher energy use. If the elasticity of demand for energy fell below -1.0, the substitution effect alone would suggest increased energy use, so we restrict our sensitivity range to ensure that it never does so. Even at -1, the output/demand effects push the rebound effect above 100%, which we consider implausible, but we include the case to illustrate what might happen.

We set the elasticity of output price with respect to the emission price, σ_i equal to the share of energy in total costs for the steel sector. Medarac et al. (2020) provide a detailed breakdown of the costs of producing iron and steel in the EU and other countries using data from 2019. For hot rolled coil, they find that in the EU27 energy costs account for 17% of total production cost, while for the production of wire rod the share of energy is 11%. Data from SteelOrbis, a market intelligence provider for the steel sector, show that the energy share was between 9-18% prior to 2022, but increased to 25-40% following the Russian invasion of Ukraine (SteelOrbis 2022). We therefore assume a central value of 0.2 and perform sensitivity analysis by multiplying it by 0.5 and 2.

For the own price elasticity of demand for steel, we follow Winters (1995) to set it to -0.3, and we assume a cross-price elasticity of 0.15.[12]

The share of domestic sales θ_i is calculated from the FIGARO input-output tables provided by Eurostat. The calculations are based on the Basic Metals sector (CPA 24).

The (bilateral) shares of world emissions s_{ij} are calculated as the energy content (sector D35) into metals production by destination. That is, if metal production in the EU uses *X* amount of energy (purchases from sector 35) and *x*% are exported to ROW, the pollution content of exports is computed as *X*x.* This method has the pitfall of assuming common technology and energy prices across countries. We check our numbers against those of Lei et al. (2023) who develop a CO_2 emissions inventory of 4,883 individual iron and steel plants around the world using detailed information on the technology used by each plant and the CO_2 emission of each technology. We then apportion the CO_2 emission by destination using destination sales shares of basic metals from the FIGARO tables. We find only minor differences between the two methods. Nonetheless, in the simulations, we check our results based on energy consumption against using the bilateral emissions shares based on the data of Lei et al. (2023). The shares are reported in Table 10.[13]

Finally, the share of emission permits cost on total energy cost $A_i^E p^E / p_i^e$ is computed as follows. Recalling that we define the price of energy as $p_i^e = p^C + A_i^E p^E$, where p^C is the price of fuel. We consider a world price of metallurgical coal p^C=\$200 per ton (the information comes from IEA (2024) and consultation of Australian coking coal market prices). Evidence suggests that burning one ton of coal produces about 2.6 tons of carbon.[14]

Hence, we set A_i^E= 2.6 for both *H* and *F*. Over the last year, the EU ETS price, or the price of permits, has been around €70 per ton of carbon, which we convert into US dollars using an exchange rate of 1.12, giving p^E=\$78.4 . Putting numbers together, we obtain a share of permits cost of energy cost of 0.5:

$$\frac{A^E p^E}{p^e} = \frac{2.6 \times \$78.4}{\$200 + 2.6 \times \$78.4} = 0.5$$

Table 9: Values of parameters used in simulations

Symbol	Description	Value	Source	Sensitivity
ϵ_i^q	Elasticity of emission demand w.r.t. output	1	Assumption	
$e_i^{p^e}$	Elasticity of energy demand w.r.t. energy price	-0.75; Sensitivity ±0.25	Wang et al. (2021)	Yes
$e_i^{A^e}$	Elasticity of emission demand w.r.t energy efficiency	0.75; Sensitivity ±0.25	Wang et al. (2021)	Yes

[12] NERA (2016, p67) states that the elasticity of demand is commonly assumed to lie between –0.2 and –0.3
[13] In this simplified model the products covered by CBAM account for all global emissions, whereas this is not true of the world.
[14] https://climate.mit.edu/ask-mit/how-can-burning-one-ton-fuel-create-more-one-ton-co2

σ_i	Elasticity of output price w.r.t. (net) energy price	0.2; Sensitivity × 2 or × 0.5	See text	Yes
$\eta_{ij}^{p_i}$	Own price elasticity of demand	-0.3	Winters (1995)	
$\eta_{ij}^{p_j}$	Cross price elasticity of demand	0.15	Assumption	
θ_i	Share of domestic sales	0.82 for the EU; 0.98 for ROW	FIGARO tables	
s_{ij}	Share of world emissions	see Table 10 below	FIGARO tables; sensitivity analysis with data from Lei et al. (2023)	Yes
$A_i^E p^E / p_i^e$	Share of emission permit cost in energy cost	0.5	Own calculations	

Table 10: Share of emissions in basic metals by destination

	a) FIGARO Tables				b) Lei et al. (2023)		
	EU	ROW	Total		EU	ROW	Total
EU to	0.068	0.013	0.081	EU to	0.055	0.011	0.066
ROW to	0.014	0.905	0.919	ROW to	0.015	0.920	0.934
Total	0.082	0.918		Total	0.070	0.930	

Source: panel (a) authors' calculations based on FIGARO tables, computing the share of energy (sector 35) embedded in basic metals (sector 24) by destination of sales. For panel (b) we compute total CO2 emissions of steel plants by country using data from Lei et al. (2023) and then apportion CO2 emission using export share by destination from the FIGARO tables.

The simulations for the emission efficiency case are summarised in Table 11. The central simulation, reported in block A, points to a 10% improvement in EU emission efficiency reducing permit prices by 15% for the Separate Markets (SM) design, and about 13% for the Combined Market (CM). All versions of the central simulations yield reductions in global emissions, with CM dominating SM both with and without an export rebate.

Looking at the sensitivity tests, the first notable feature in Table 11 is the variance across simulations in the permit price change (block B).[15] This is driven by the elasticity of demand for energy: when this is (absolutely) smaller, the demand curve for permits in the Figures in Section 1 above becomes steeper, so finding an intersection with the vertical supply curve (the cap) requires a larger price change. A change of one standard deviation in the energy elasticity produces a 0.95 standard deviation change in the permit price compared with less than 0.15 for the elasticity of output prices to total energy prices and much less for other variables.[16]

For emissions (block C), on the other hand, the sensitivity of output prices to emissions prices is the stronger influence because it determines the quantities of goods produced and thus the energy used. This is most obvious when there is no export rebate (rows 2 and 4): a low elasticity of energy

[15] The full set of simulation results is given in the Appendix.

[16] If we allowed the elasticity of demand for energy to become even smaller, the effect would be stronger – for instance, with an elasticity of -0.375 (half our central case), a 10% improvement in energy efficiency would see permit prices falling by over 40%.

demand (which produces a large decline in the permit price) plus high sensitivity of output prices to emissions prices produces very large reductions in global emissions considering that the EU accounts for only 7% to 8% of global emissions. In the two most extreme cases, the reductions are very slightly larger for SM than CM, the only exceptions to the result that CM dominates SM in terms of abatement. These reductions derive mainly from sales in the rest of the world (RoW): the cap fixes (some part) of EU emissions, but lower permit costs in the EU allow it to out-compete some RoW domestic sales.

Table 11: Change in emission efficiency

Permit Markets	Export rebate	No. of simula-tions	(A) Central simulation (% changes)		(B) Range of permit prices (% changes)			(C) Range of global emissions (% changes)		
			Permit price	Global emissions	minimum	median	maximum	minimum	median	maximum
Separate (SM)	Yes	18	-15.26	-0.045	-28.54	-15.26	-8.30	-0.070	-0.034	0.001
	No	18	-15.15	-0.258	-28.39	-15.15	-8.22	-0.848	-0.260	-0.064
Combined (CM)	Yes	18	-12.64	-0.129	-23.58	-12.39	-6.68	-0.129	-0.117	-0.105
	No	18	-12.92	-0.311	-24.14	-12.70	-6.84	-0.834	-0.311	-0.123

The results with the export rebate show much smaller reductions in global emissions and much less variation. Indeed, those for CM (row 3) reflect the facts that EU emissions are fixed by the cap and nothing disturbs prices and quantities in RoW. This makes the result quite independent of the elasticities: it arises solely because the EU emits less on its (unchanged level of) exports, the range arising only because the two estimates of global emissions shares differ slightly.

The SM design with an export rebate produces noticeably smaller declines in emissions than the CM design, but these do vary with the elasticity of energy demand, with smaller elasticities producing smaller emissions effects. This is because the change in global emissions is composed of two parts: changes associated with H sales to F, and with F sales to H (see Table 1). The former is given just by the change in emissions efficiency, which is independent of the elasticities. The latter, however, depends on the relative competitiveness of F in market H, which depends on how much the change in the permit price (which affects both H's and F's final prices) differs from the change in H's emission efficiency (affecting only H's final price). A larger absolute elasticity produces smaller changes in the permit price, giving a large competitiveness advantage to H and a large reduction of F sales to H. A small absolute elasticity, on the other hand, produces larger permit price changes, so that H's competitiveness increases by less, and F sales to H see a smaller reduction.

The main question we wish to answer, however, is not the sensitivity of results with respect to different parameter values, but whether the design of the CBAM matters; that is, whether, as we suggest, CM offers advantages over SM. Table 11 shows that for SM with a rebate, the change in global emissions following a 10% improvement in emissions efficiency just tips over into positive territory. This occurs with the smallest (absolutely) elasticities of demand for energy and of output prices with respect to energy costs with the alternative emissions weights across markets.[17] It never

[17] A smaller elasticity of energy demand implies a larger decline in permit prices and hence encourages greater permit purchases by RoW. EU suppliers benefit from both the decline in permit price and the improved efficiency, but the extent to which the latter confers competitive advantage in the output market is greater the greater is the sensitivity of output to energy prices. Thus, when that sensitivity is low, domestic sales in the EU get less benefit from efficiency and exporters from RoW can capture a larger market share, and hence produce more emissions. The LEI et al. estimated shares of global emissions are slightly larger for RoW-to-EU sales than

happens with the combined market (CM) design which always delivers material declines in global emissions in our simulations. For example, using the central parameter values (block A), CM offers smaller permit price changes in response to the efficiency shock and materially greater global emissions reductions (rows 1 and 2 vs. 3 and 4).

The CM runs suggest smaller permit price reductions than their equivalent SM runs and produce larger declines in global emissions than SM in all cases except in the two extreme runs noted above. These last are the simulations with the strongest abatements of global emissions and, in them, SM suggests greater global abatement by 0.004 percentage points with FIGARO weights and 0.019 ppts with Lei et all weights. Averaging results across runs within each design shows CM offering better emissions outcomes than SM by 0.08 ppts with the rebate and 0.04 ppts without it.

Table 12 repeats Table 11 but for a 10% improvement in energy efficiency – the amount of energy required to produce a given output given other factor inputs.

Table 12: Change in energy efficiency

Permit Markets	Export rebate	No. of simula-tions	(A) Central simulation (% changes)		(B) Range of permit prices (% changes)			(C) Range of global emissions (% changes)		
			Permit price	Global emissions	minimum	median	maximum	minimum	median	maximum
Separate (SM)	Yes	18	-4.87	-0.241	-18.25	-4.87	2.26	-0.565	-0.243	-0.066
	No	18	-4.84	-0.314	-18.16	-4.84	2.24	-0.873	-0.317	-0.138
Combined (CM)	Yes	18	-4.15	-0.264	-15.15	-4.08	1.67	-0.539	-0.267	-0.132
	No	18	-4.22	-0.329	-15.50	-4.16	1.73	-0.864	-0.331	-0.133

It is immediately obvious that the price changes are smaller for changes in energy efficiency than for those in emissions efficiency. This is because, whereas for emissions efficiency, the price of permits has to drive all of the adjustment, in the energy case improved efficiency reduces costs directly (and hence prices), which ceteris paribus increases home sales and energy demand. This mitigates the required reduction in permit prices to balance the home market. In addition, there are stronger effects in EU exports markets (i.e. the Rest of the World, RoW): in the absence of the rebate, export prices fall both because less energy is required and because permit prices fall; if there is an export rebate, changes in emissions efficiency have no effect on export prices but those in energy efficiency still have a direct effect.

The key difference between emissions and energy efficiency changes lies in their effects on output prices and hence on quantities. An improvement in emissions efficiency affects behaviour via the share of output prices stemming from having to purchase emission permits – which we have estimated as one half. A change in energy efficiency affects both the quantity of energy needed and the number of permits and so has, loosely speaking, twice the impact.

It is clear from block (B) column 'maximum price change' that an increase in energy efficiency sometimes increases the permit price: this is when the elasticity of energy demand is -1. As noted above, this is because an elasticity of -1 implies that an improvement in energy efficiency of *x*% leads, via substitution for other factors, to an increase in energy demand of *x*%, leaving energy use for a given output unchanged. Meanwhile the effect of efficiency on output prices increases output

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the ones from FIGARO and with them these output effects outweigh the efficiency increase on EU exports to RoW.

and hence energy demand. Overall, then, with this elasticity an improvement in energy efficiency leads to greater energy demand and hence greater demand for emission permits and an increase in the permit price. As we also noted above, none of the recent literature on the so-called 'rebound effect' suggests this result, so we consider these simulations implausible. The implausibility is also present in the results reported above for emissions efficiency, but is not obvious because emissions prices account for only half the change in the total price of energy and so the substitution of energy for other factors is only half as strong as with energy efficiency.

In terms of global emissions, we always see larger declines with energy efficiency changes than with emissions efficiency changes, more markedly in the presence of an export rebate. In this case, with the CM design, emissions for the EU market are capped, so the only effects occur in the RoW market: EU exports become more competitive as energy efficiency reduces their prices, and this effect is stronger the larger the elasticity of output prices with respect to energy prices. Since EU production is less emission-prone, global emissions benefit from the resulting displacement of RoW sales. In the SM case, only the emissions due to EU domestic sales are capped and the decline in the permit price encourages greater RoW exports to the EU, partially offsetting the benefits reaped in the RoW market. [In the implausible case in which the permit price increases, RoW exports and emissions are curtailed, actually improving on the CM case.]

Without the rebate, the results for energy efficiency are similar to those for emissions efficiency, including the extreme cases in which abatement under SM is very slightly stronger than under CM and adding the implausible cases just noted where the elasticity of energy demand is -1. In all other runs, CM returns larger declines in global emissions than does SM. Averaging over the plausible runs CM offers better emissions outcomes than SM by 0.04 ppts with the rebate and 0.02 ppts without it.

Overall, while we would not suggest taking these simulations or the model literally, the CM design consistently offers better abatement and smaller permit price responses to emissions efficiency improvements than the currently preferred SM model for CBAM over a wide range parameter and data combinations. It also suggests slightly less variance across different parameter values, presumably reflecting the more extensive reach across markets in which adjustment can take place.

4 The practical details

In practice the creation of a combined market for the ETS and the CBAM amounts to rolling the CBAM market into the already functional ETS market. In this market, allowances (permits in our terminology) are issued by auction or as free allowances and may then be sold, both spot and future, on secondary markets. Purchases in the secondary market can be made continuously via brokers or on-line trading sites and in relatively small amounts. Permits are essentially treated as financial instruments, for which we have plenty of experience – for example, large importers may well hedge their currency transactions and small importers purchase retail amounts of foreign exchange; ETS/CBAM need be no different.

Incorporating importers into the ETS system may require some small adjustments. First, ETS allowances are infinitely-lived and it is not clear (to us) whether that is the intention for CBAM certificates or not. Given the long half-life of carbon dioxide, there seems no objection to extending this to imports. Second, international traders may require only small numbers of permits, so one would need to ensure that at least some on-line trading sites and brokers could deal with small 'retail' transactions. We already provide that for foreign exchange, so this is not technically insurmountable for carbon permits. Third, once issued, the surrender of permits by importers could presumably be combined with that for producers, but if it was felt that other elements required a bespoke system, the system currently planned for CBAM certificates could still be used.

In considering whether to have one market or two separate markets for emission permits, The European Parliament Committee on Economic and Monetary Affairs opined that combination 'entail[ed] additional technical challenges, such as ensuring price stability … and introducing safeguards to avoid the risk of potential market interference.'[18] Garicano (2021) additionally expressed concerns about mixing firm-based and product-based processes in one market, the volatility of imports, and 'the political character of quota distribution among countries'.

These concerns are legitimate but can be answered. Obviously, the cap would have to be larger than an ETS-only cap and, as is the case now, the Market Stability Reserve could be used to stabilise prices.[19] Market interference is always a concern, but the argument implies that this is greater when importers are concerned than when only domestic producers are concerned. A larger (combined) market is more difficult to manipulate and probably more stable, and if the limited number of importers is a problem, it is a more extensive one than just in the market for permits. It implies a fear that only a small number of agents that can actually import CBAM-covered goods, which if true should wave red flags for the management of the imports per se more than for the market for permits. Development economists have long recognised that monopoly power among traders is one of the most restrictive import barriers there is, e.g. Yeats (1978). Garicano suggests that concerns over anti-competitive bidding for permits can be managed by limiting importers' purchases to some measure related to their historical trade.

The complexity of mixing firm-based (ETS) and product-based (CBAM) systems of managing emission permits is inherent in any combination of an ETS and a CBAM. Whichever market arrangement is chosen, someone has to determine the carbon permit requirements for individual products by customs line. If it can be managed for the current CBAM plan, we can see no additional problem with having a combined market for permits. On volatility, it is not clear that imports are more volatile than domestic output or that introducing them will exacerbate as opposed to offset domestic shocks. Besides, pure volatility is just a matter of timing, which the market reserve can cope with. Finally, the CBAM explicitly does not have country quotas.

The EU has quite involved procedures for determining the number of allowances to issue in the ETS, and these would require modification to fix a combined cap. The latter might be thought to pose greater international diplomatic challenges, but that is not obvious to us. Exporters to the EU/UK are already impacted by the CBAM; all our proposal is doing is changing the mechanism through which impact occurs. Moreover, EU aggregate emissions from the consumption of goods is a solely EU objective and involves no more pain for foreign producers that does imposing a border levy.

As we noted above, if export rebates are to be granted there is the practical problem of dealing with exports via distributors - UK data suggest that between a third and a half of UK exports of iron and steel and articles of iron and steel occur through distributors.

Finally, as we noted in the introduction, with full information one could manipulate the supply of ETS permits in the current CBAM design (SM) so that it replicates the outcome of our combined market (CM). Indeed, the Market Stability Reserve (MSR) is designed precisely to manage undesirable price fluctuations in the ETS price of allowances. However, the information requirements are truly massive and the MSR is designed to manage short-run fluctuations in order to provide some predictability for

[18] Paragraph 3 of Committee on Economic and Monetary Affairs opinion in European Parliament (2021)
[19] See European Commission (n.d.)

firms seeking to adjust to emissions charges. To adapt it to avoid the potential perversity we outline would basically turn the ETS into a fixed price system, undermining the advantage of the cap-and-trade approach in which science determines the desired level of emissions and the market determines the price and allocation.

Overall, our judgement is that the challenges are not insurmountable and are clearly outweighed by the economic efficiency and climate policy gains of combining the markets for permits in the ETS and the CBAM.

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6 Appendix

6.1 Demand for permits

To find the change in the permit price, we start from the following system of linear equations:

$$\begin{cases} \hat{e}_{ij} = \epsilon_i^q \hat{q}_{ij} + \epsilon_i^{p^e} \dfrac{A_i^E p^E}{p^e} \left(\hat{A}_i^E + \hat{p}^E\right) + \epsilon_i^{A^e} \hat{A}_i^e - \hat{A}_i \\ \hat{q}_i = \theta_i \hat{q}_{ii} + (1-\theta_i)\hat{q}_{ij} \\ \hat{q}_{ij} = \eta_{ij}^{p_i}(\hat{p}_i + \hat{\tau}_{ij}) + \eta_{ij}^{p_j}(\hat{p}_j + \hat{\tau}_{jj}) \\ \hat{p}_{ij} = \sigma_i \dfrac{A_i^E p^E}{p^e} \left(\hat{A}_i^E + \hat{p}^E\right) + \sigma_i \hat{A}_i^e - \hat{A}_i + \hat{\tau}_{ij} \end{cases}$$

together with the permit market equilibrium condition $\widehat{Permits} = \hat{E}^S$ where $\widehat{Permits}$ is the demand for emissions permits covered by the cap-and-trade system. The demand of permit will change depending on the policy scenario.

6.2 Separate Markets

6.2.1 Separate Markets with export rebate

Under Separate Markets, the only demand for permits comes from H's domestic sales:

$$\widehat{Permits} = \hat{e}_{HH} + \hat{A}_H^E$$

Substituting the change in energy demand $\hat{e}_{HH}$ we obtain:

$$\widehat{Permits} = \epsilon_H^q \left(\eta_{HH}^{p_H} \hat{p}_{HH} + \eta_{HH}^{p_F} \hat{p}_{FH}\right) + \epsilon_H^{p^e} \frac{A_H^E p^E}{p^e} \left(\hat{A}_H^E + \hat{p}^E\right) + \epsilon_H^{A^e} \hat{A}_H^e - \hat{A}_H + \hat{A}_H^E$$

6.2.2 Separate Markets without export rebate

If there is no export rebate, the demand for permits depends on both H's domestic and foreign sales:

$$\widehat{Permits} = \hat{e}_H + \hat{A}_H^E$$

The change in H's energy demand can be expressed as:

$$\hat{e}_H = \theta_H \left[\epsilon_H^q \left(\eta_{HH}^{p_H} \hat{p}_{HH} + \eta_{HH}^{p_F} \hat{p}_{FH} \right) + \epsilon_H^{p^e} \frac{A_H^E p^E}{p^e} \left(\hat{A}_H^E + \hat{p}^E \right) \right] + (1 - \theta_H) \left[\epsilon_H^q \left(\eta_{HF}^{p_H} \hat{p}_{HF} + \eta_{HF}^{p_F} \hat{p}_{FF} \right) + \epsilon_H^{p^e} \frac{A_H^E p^E}{p^e} \left(\hat{A}_H^E + \hat{p}^E \right) \right] + \epsilon_H^{A^e} \hat{A}_H^e$$

And simplifying we obtain:

$$\hat{e}_H = \epsilon_H^q \left[\theta_H \left(\eta_{HH}^{p_H} \hat{p}_{HH} + \eta_{HH}^{p_F} \hat{p}_{FH} \right) + (1 - \theta_H) \left(\eta_{HF}^{p_H} \hat{p}_{HF} + \eta_{HF}^{p_F} \hat{p}_{FF} \right) \right] + \epsilon_H^{p^e} \frac{A_H^E p^E}{p^e} \left(\hat{A}_H^E + \hat{p}^E \right) + \epsilon_H^{A^e} \hat{A}_H^e$$

6.2.3 Separate Markets general formulation

We can write a general formulation for the change in the permits demand under separate markets as follows:

$$\widehat{Permits} = (1 - \mathbb{1}(EX)) \hat{e}_{HH} + \mathbb{1}(EX) \hat{e}_H + \epsilon_H^{A^e} \hat{A}_H^e + \hat{A}_H^E$$

Where $\mathbb{1}(EX)$ is an indicator that equals one if the policy covers exports (=no rebate) and zero otherwise. Substituting $\hat{e}_H = \theta_H \hat{e}_{HH} + (1 - \theta_H) \hat{e}_{HF}$ and rearranging we obtain:

$$\widehat{Permits} = [1 - \mathbb{1}(EX)(1 - \theta_H)] \hat{e}_{HH} + \mathbb{1}(EX) \hat{e}_{HF} + \epsilon_H^{A^e} \hat{A}_H^e + \hat{A}_H^E$$

Now substitute the definitions of $\hat{e}_{HH}$ and $\hat{e}_{HF}$:

$$\widehat{Permits} = [1 - \mathbb{1}(EX)(1 - \theta_H)] \left[\epsilon_H^q \left(\eta_{HH}^{p_H} \hat{p}_{HH} + \eta_{HH}^{p_F} \hat{p}_{FH} \right) + \epsilon_H^{p^e} \frac{A_H^E p^E}{p^e} \left(\hat{A}_H^E + \hat{p}^E \right) \right] + \mathbb{1}(EX)(1 - \theta_H) \left[\epsilon_H^q \left(\eta_{HF}^{p_H} \hat{p}_{HF} + \eta_{HF}^{p_F} \hat{p}_{FF} \right) + \epsilon_H^{p^e} \frac{A_H^E p^E}{p^e} \left(\hat{A}_H^E + \hat{p}^E \right) \right] + \epsilon_H^{A^e} \hat{A}_H^e + \hat{A}_H^E$$

As F domestic sales never pay an emission permit price, we have $\hat{p}_{FF} = 0$. Given no change in F emission efficiency, $\hat{p}_{FH}$ depends solely on the permit price $\hat{p}^E$, and we have $\hat{p}_{FH} = \sigma_F \frac{A_F^E p^E}{p^e} \hat{p}^E$. On the other hand, given no change in trade costs, $\hat{p}_{HH} = \sigma_H \frac{A_H^E p^E}{p^e} \left(\hat{A}_H^E + \hat{p}^E \right) + \sigma_H \hat{A}_H^e$. Substituting and rearranging we have:

$$\widehat{Permits} = [1 - \mathbb{1}(EX)(1 - \theta_H)] \epsilon_H^q \left(\eta_{HH}^{p_H} \sigma_H \frac{A_H^E p^E}{p^e} \left(\hat{A}_H^E + \hat{p}^E \right) + \eta_{HH}^{p_F} \sigma_F \frac{A_F^E p^E}{p^e} \hat{p}^E \right) + \mathbb{1}(EX)(1 - \theta_H) \epsilon_H^q \eta_{HF}^{p_H} \sigma_H \frac{A_H^E p^E}{p^e} \left(\hat{A}_H^E + \hat{p}^E \right) + \epsilon_H^{p^e} \frac{A_H^E p^E}{p^e} \left(\hat{A}_H^E + \hat{p}^E \right) + \left\{ [1 - \mathbb{1}(EX)(1 - \theta_H)] \epsilon_H^q \eta_{HH}^{p_H} \sigma_H + \mathbb{1}(EX)(1 - \theta_H) \epsilon_H^q \eta_{HF}^{p_H} \sigma_H + \epsilon_H^{A^e} \right\} \hat{A}_H^e + \hat{A}_H^E$$

We can now set the change in permits demand equal to the change in the cap and solve for the change in price of permits:

$$\hat{p}^{E,SM} = \frac{\hat{E}^s}{[1-\mathbb{1}(EX)(1-\theta_H)]\epsilon_H^q\left(\eta_{HH}^{p_H}\sigma_H\frac{A_H^E p^E}{p^e}+\eta_{HH}^{p_F}\sigma_F\frac{A_F^E p^E}{p^e}\right)+\mathbb{1}(EX)(1-\theta_H)\epsilon_H^q\eta_{HF}^{p_H}\sigma_H\frac{A_H^E p^E}{p^e}+\epsilon_H^{p^e}\frac{A_H^E p^E}{p^e}}$$
$$-\frac{1+[1-\mathbb{1}(EX)(1-\theta_H)]\epsilon_H^q\eta_{HH}^{p_H}\sigma_H\frac{A_H^E p^E}{p^e}+\mathbb{1}(EX)(1-\theta_H)\epsilon_H^q\eta_{HF}^{p_H}\sigma_H\frac{A_H^E p^E}{p^e}+\epsilon_H^{p^e}\frac{A_H^E p^E}{p^e}}{[1-\mathbb{1}(EX)(1-\theta_H)]\epsilon_H^q\left(\eta_{HH}^{p_H}\sigma_H\frac{A_H^E p^E}{p^e}+\eta_{HH}^{p_F}\sigma_F\frac{A_F^E p^E}{p^e}\right)+\mathbb{1}(EX)(1-\theta_H)\epsilon_H^q\eta_{HF}^{p_H}\sigma_H\frac{A_H^E p^E}{p^e}+\epsilon_H^{p^e}\frac{A_H^E p^E}{p^e}}\hat{A}_H^E$$
$$-\frac{[1-\mathbb{1}(EX)(1-\theta_H)]\epsilon_H^q\eta_{HH}^{p_H}\sigma_H+\mathbb{1}(EX)(1-\theta_H)\epsilon_H^q\eta_{HF}^{p_H}\sigma_H+\epsilon_H^{A^e}}{[1-\mathbb{1}(EX)(1-\theta_H)]\epsilon_H^q\left(\eta_{HH}^{p_H}\sigma_H\frac{A_H^E p^E}{p^e}+\eta_{HH}^{p_F}\sigma_F\frac{A_F^E p^E}{p^e}\right)+\mathbb{1}(EX)(1-\theta_H)\epsilon_H^q\eta_{HF}^{p_H}\sigma_H\frac{A_H^E p^E}{p^e}+\epsilon_H^{p^e}\frac{A_H^E p^E}{p^e}}\hat{A}_H^e$$

6.3 Combined Markets

6.3.1 Combined Markets with export rebate

Under Combined Markets with the export rebate, the demand for permits comes from sales in market H:

$$\widehat{Permits} = \tilde{s}_H\left(\hat{e}_{HH}+\hat{A}_H^E\right)+(1-\tilde{s}_H)\hat{e}_{FH}$$

The changes in H and F 's demands are weighted by their initial shares, $\tilde{s}_H$, which we will define later. We know that:

$$\hat{e}_{FH} = \epsilon_F^q\left(\eta_{FH}^{p_F}\hat{p}_{FH}+\eta_{FH}^{p_H}\hat{p}_{HH}\right)+\epsilon_F^{p^e}\frac{A_F^E p^E}{p^e}\hat{p}^E$$

while the change in H 's domestic sales is the same as above.

6.3.2 Combined Markets without export rebate

Without an export rebate, we also have to account for H's exports in the demand for permits:

$$\widehat{Permits} = \tilde{s}_H\left(\theta_H\hat{e}_{HH}+(1-\theta_H)\hat{e}_{HF}+\hat{A}_H^E\right)+(1-\tilde{s}_H)\hat{e}_{FH}$$

Hence we can combine the demand for permits under CM with and without rebate:

$$\widehat{Permits} = [1-\mathbb{1}(EX)(1-\theta_H)]\tilde{s}_H\hat{e}_{HH}+\mathbb{1}(EX)\tilde{s}_H(1-\theta_H)\hat{e}_{HF}+\tilde{s}_H\hat{A}_H^E+(1-\tilde{s}_H)\hat{e}_{FH}$$

Substituting the definitions of the change in energy demands and following the same logic used in the Separate Markets case, we can solve for the price of permits to obtain:

$$\hat{p}^E = \frac{\hat{E}^s}{\varepsilon} - \frac{\tilde{s}_H\left[1+[1-\mathbb{1}(EX)(1-\theta_H)]\epsilon_H^q\eta_{HH}^{p_H}\sigma_H\frac{A_H^E p^E}{p^e}+\mathbb{1}(EX)(1-\theta_H)\epsilon_H^q\eta_{HF}^{p_H}\sigma_H\frac{A_H^E p^E}{p^e}+\epsilon_H^{p^E}\right]+(1-\tilde{s}_H)\epsilon_F^q\eta_{FH}^{p_H}\sigma_H\frac{A_F^E p^E}{p^e}}{\varepsilon}\hat{A}_H^E$$
$$-\frac{\tilde{s}_H\left[[1-\mathbb{1}(EX)(1-\theta_H)]\epsilon_H^q\eta_{HH}^{p_H}\sigma_H+\mathbb{1}(EX)(1-\theta_H)\epsilon_H^q\eta_{HF}^{p_H}\sigma_H+\epsilon_H^{A^e}\right]+(1-\tilde{s}_H)\epsilon_F^q\eta_{FH}^{p_H}\sigma_H}{\varepsilon}\hat{A}_H^e$$

With the denominator defined as:

$$\varepsilon = \tilde{s}_H \left[\left(1 - \mathbb{1}(EX)(1-\theta_H)\right)\epsilon_H^q \left(\eta_{HH}^{p_H} \sigma_H \frac{A_H^E p^E}{p^e} + \eta_{HH}^{p_F} \sigma_F \frac{A_F^E p^E}{p^e} \right) \mathbb{1}(EX)(1-\theta_H)\epsilon_H^q \eta_{HF}^{p_H} \sigma_H \frac{A_H^E p^E}{p^e} + \epsilon_H^{p^e} \frac{A_H^E p^E}{p^e} \right] + (1-\tilde{s}_H) \left[\epsilon_F^q \left(\eta_{FH}^{p_F} \sigma_F \frac{A_F^E p^E}{p^e} + \eta_{FH}^{p_H} \sigma_H \frac{A_H^E p^E}{p^e} \right) + \epsilon_F^{p^E} \right]$$

And defining $\epsilon_i^{p^E} = \epsilon_i^{p^e} \frac{A_i^E p^E}{p^e}$.

6.4 Simulation results

Table 13: Full set of simulation results

Parameter values				10% improvement in emissions efficiency			10% improvement in energy efficiency	
emission shares figaro = F Lei = L	elasticity of energy demand	elasticity of output price to energy price		EU permit price % change	Global Emissions % change		EU permit price % change	Global Emissions % change
Separate Markets (SM) with no export rebate								
F	-0.5	0.1		-28.39	-0.156		-18.16	-0.194
F	-0.75	0.1		-15.89	-0.089		-5.73	-0.145
F	-1	0.1		-9.53	-0.064		0.59	-0.138
F	-0.5	0.2		-26.90	-0.400		-16.44	-0.436
F	-0.75	0.2		-15.15	-0.258		-4.84	-0.314
F	-1	0.2		-9.08	-0.194		1.16	-0.269
F	-0.5	0.4		-24.18	-0.834		-13.31	-0.859
F	-0.75	0.4		-13.77	-0.569		-3.17	-0.619
F	-1	0.4		-8.22	-0.436		2.24	-0.508
L	-0.5	0.1		-28.39	-0.159		-18.16	-0.197
L	-0.75	0.1		-15.89	-0.090		-5.73	-0.147
L	-1	0.1		-9.53	-0.065		0.59	-0.140
L	-0.5	0.2		-26.90	-0.407		-16.44	-0.443
L	-0.75	0.2		-15.15	-0.262		-4.84	-0.319
L	-1	0.2		-9.08	-0.197		1.16	-0.273
L	-0.5	0.4		-24.18	-0.848		-13.31	-0.873
L	-0.75	0.4		-13.77	-0.578		-3.17	-0.629
L	-1	0.4		-8.22	-0.443		2.24	-0.516
Separate Markets (SM) with export rebate								
F	-0.5	0.1		-28.54	-0.024		-18.25	-0.066
F	-0.75	0.1		-15.95	-0.042		-5.75	-0.102
F	-1	0.1		-9.56	-0.060		0.59	-0.138

F	-0.5	0.2		-27.17	-0.027		-16.60	-0.205
F	-0.75	0.2		-15.26	-0.045		-4.87	-0.241
F	-1	0.2		-9.13	-0.063		1.17	-0.277
F	-0.5	0.4		-24.64	-0.034		-13.57	-0.481
F	-0.75	0.4		-13.95	-0.052		-3.21	-0.517
F	-1	0.4		-8.30	-0.070		2.26	-0.554
L	-0.5	0.1		-28.54	0.001		-18.25	-0.068
L	-0.75	0.1		-15.95	-0.017		-5.75	-0.105
L	-1	0.1		-9.56	-0.035		0.59	-0.141
L	-0.5	0.2		-27.17	-0.002		-16.60	-0.209
L	-0.75	0.2		-15.26	-0.020		-4.87	-0.246
L	-1	0.2		-9.13	-0.038		1.17	-0.283
L	-0.5	0.4		-24.64	-0.008		-13.57	-0.492
L	-0.75	0.4		-13.95	-0.027		-3.21	-0.529
L	-1	0.4		-8.30	-0.045		2.26	-0.565
Combined Market (CM) with no export rebate								
F	-0.5	0.1		-24.14	-0.232		-15.50	-0.241
F	-0.75	0.1		-13.51	-0.160		-4.92	-0.169
F	-1	0.1		-8.11	-0.123		0.46	-0.133
F	-0.5	0.2		-22.93	-0.447		-14.13	-0.463
F	-0.75	0.2		-12.92	-0.311		-4.22	-0.329
F	-1	0.2		-7.75	-0.241		0.90	-0.259
F	-0.5	0.4		-20.72	-0.834		-11.64	-0.859
F	-0.75	0.4		-11.81	-0.592		-2.91	-0.622
F	-1	0.4		-7.07	-0.463		1.73	-0.496
L	-0.5	0.1		-23.30	-0.230		-14.97	-0.241
L	-0.75	0.1		-13.04	-0.159		-4.76	-0.171
L	-1	0.1		-7.83	-0.123		0.43	-0.135
L	-0.5	0.2		-22.14	-0.443		-13.67	-0.464
L	-0.75	0.2		-12.48	-0.310		-4.10	-0.332
L	-1	0.2		-7.48	-0.241		0.84	-0.264
L	-0.5	0.4		-20.03	-0.828		-11.31	-0.864
L	-0.75	0.4		-11.42	-0.591		-2.86	-0.631
L	-1	0.4		-6.84	-0.464		1.63	-0.507
Combined Market (CM) with export rebate								
F	-0.5	0.1		-23.58	-0.129		-15.15	-0.132
F	-0.75	0.1		-13.18	-0.129		-4.81	-0.132
F	-1	0.1		-7.90	-0.129		0.44	-0.132
F	-0.5	0.2		-22.49	-0.129		-13.88	-0.264
F	-0.75	0.2		-12.64	-0.129		-4.15	-0.264
F	-1	0.2		-7.57	-0.129		0.86	-0.264
F	-0.5	0.4		-20.50	-0.129		-11.56	-0.528

F	-0.75	0.4		-11.63	-0.129		-2.91	-0.528
F	-1	0.4		-6.94	-0.129		1.67	-0.528
L	-0.5	0.1		-22.62	-0.105		-14.55	-0.135
L	-0.75	0.1		-12.65	-0.105		-4.63	-0.135
L	-1	0.1		-7.58	-0.105		0.41	-0.135
L	-0.5	0.2		-21.59	-0.105		-13.36	-0.270
L	-0.75	0.2		-12.14	-0.105		-4.01	-0.270
L	-1	0.2		-7.27	-0.105		0.80	-0.270
L	-0.5	0.4		-19.70	-0.105		-11.18	-0.539
L	-0.75	0.4		-11.18	-0.105		-2.85	-0.539
L	-1	0.4		-6.68	-0.105		1.55	-0.539

6.5 The UK position

We end with a brief note on the position of the UK, which also has an ETS and will introduce a CBAM. First, the UK has decided to levy its CBAM as a border charge when covered imports arrive, with the price based on the ETS price in the previous quarter – HM Treasury (2024, Government Response). This is essentially the same as the EU's separate markets approach, for the levy is applied to as many imports as choose to turn up on the border given the pre-declared level of the levy. Thus, all the structures discussed above apply to the UK as well as to the EU.

Second, the UK and EU have declared their intention to link their ETSs, with obvious advantages in terms of creating larger and more stable market for allowances and avoiding the application of CBAM charges and bureaucracy on their mutual trade – HM Government (2025). It is not yet clear whether the combined number of allowances will be jointly determined and then allocated between EU and UK issuers or whether (as we have occasionally heard) each jurisdiction will decide its own issuance separately, in which case questions of free-riding abound.

Third, no mention has been made of the natural corollary of combining or aligning the UK and EU CBAMs, although informal comments suggest that it is not on the agenda. Combining the CBAMs will be complex, not least because two different customs authorities will be involved, but it is certainly worth pursuing. To the extent that the two CBAMs have different coverage (both authorities are talking about extending coverage), they will require rules of origin on the border to prevent traders evading CBAM charges by routing goods through the place with the less extensive coverage. Regular customs involves such ROOs, but it is not clear that 'regular' ROOs will identify loopholes in the CBAM accounting (e.g. identifying embedded emissions in inputs). If any administrative or reporting details differ between the two CBAMS, traders will have to prepare two lots of paperwork and submit them in different places – and this could well lead overseas traders just not to bother with the smaller UK market. At the minimum the UK and EU should agree the form and content of CBAM declarations so that the same form meets both sets of requirements and ideally they should recognise that verification by one of the UK and EU will satisfy the other.

A further complication is that if the EU offers a rebate to exporters, as it now plans, and the UK has a separate CBAM, the EU will either have to exclude exports to the UK from the rebate or the UK will have to start levying the CBAM on imports from the EU – a massive and probably highly contentious task. Overall, we suspect that in the long run it will prove insurmountably complex to have combined ETSs and separate CBAMs.

Finally, the UK has expended considerable effort designing its CBAM and, if we are frank, in differentiating it from the EU's. Some differences are merely superficial (e.g. referring to 'world averages' rather than 'global averages'), but others are substantive, such as the retention of some free allowances and the design of the threshold for CBAM liability, in which the UK has come up with a third-best answer to replace the EU's second-best one – see Winters and Zhang (2025), European Commission (2025a) and TAPP (2025). Pooling resources to create a single ETS and single CBAM seems to us an obvious step.