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. For charging imports a corresponding emission price, they propose Carbon Border Adjustment Mechanisms that take the domestic price and apply it to an unlimited volume of imports. This approach sets the carbon price based solely on the domestic side of the market, leaving the total emissions driven by EU or UK consumption indeterminate. In particular, a technological change reducing the demand for domestic emissions would lower the carbon price, increase imports, and possibly increase global emissions. This paper offers graphical and analytical expositions of this problem and through simulations shows that this perverse effect is likely. It also assesses the practical challenges of combining the ETS and CBAM markets as perfectly manageable.

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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 from 2027 and is consulting on the details. Both still have details to fill in, but the broad outlines are reasonably clear.

The objectives of the CBAM are threefold. First, the EU (UK) charges EU firms for the greenhouse gases (shorthand – carbon) they emit through its Emissions Trading System (ETS), and the CBAM is designed to charge similarly for the carbon embodied in imports. It thus aims to ensure that, for the products included in the CBAM's remit, every unit of consumption pays the same cost of emissions regardless of origin. Second, by levelling the playing field in the domestic market between local and imported goods it aims to prevent carbon leakage. Third, it hopes to incentivise exporters abroad to reduce their emissions.

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 is considering making 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.

This paper explores the implications of this prima facie perverse way of proceeding. It is more than a mere academic curiosity. The Government estimates that over half of the emissions embodied in England's consumption of goods come from imports.

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 consumption 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 interest is if technical progress in the EU/UK- i.e. in the CBAM country - reduces the demand for emissions. Under current plans this would reduce the ETS permit price and hence the price of CBAM permits. This, in turn, would reduce the price of imports and the resulting increase in the volume of imports (i.e. production abroad) could increase foreign emissions by more than the decline in emissions triggered by the original technical progress. That is, despite emission-saving innovation, global emissions could increase!

Our paper provides a simple graphical demonstration of this danger. It then provides a more complete, albeit still simplified, model of the economy and shows that with separate ETS and CBAM permit markets it is quite possible that the result outlined above occurs. Next, we simulate the model and show that with plausible ranges of parameters, partly based on the iron and steel sector (the largest sector affected by CBAM), the outcome is perverse more often than not. 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.

Our analysis suggests that for a relatively simple institutional change, the EU could place carbon pricing on a much more secure footing and eliminate a possible perversity in its net zero policies. The UK is still debating the form of its CBAM, and we would urge it to consider a combined market from the start. At the same time, we recognise that the benefits of aligning with the EU may well outweigh those of a combined market implemented by the UK alone, even if this entailed separate markets. Ideally, there would be one market combining the EU and the UK and covering both the ETS and the CBAM.

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). 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 is consulting on the details - HM Treasury and HM Revenue and Customs (2024). The EU still has some details to fix and the UK even more, but the broad outlines are reasonably clear.

The logic of the CBAM is potentially threefold:

1. The EU charges firms for the greenhouse gases (shorthand – carbon) 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).

2. If domestic producers face charges that imports do not, *ceteris paribus*, they suffer a loss of competitiveness as demand shifts to imports – so-called carbon leakage. This undermines the climate objectives of the ETS because it shifts demand from 'cleaner' to 'dirtier' varieties. The CBAM aims to offset this effect, at least 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 decide upon).

3. If emissions lead to charges on imports into the EU, there is an incentive for exporters to reduce emissions. This contributes to the EU's objective of reducing global warming.

Thus, 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.

The ETS, in both the EU and the UK, recognises the need to cut greenhouse gas emissions in order to slow global warming and proceeds via a cap-and-trade system. 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 (which also allows reselling between agents).[2]

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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.

Everyone bidding 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 has proposed separate markets with importers buying CBAM permits from the authorities at the price determined by the domestic market for ETS permits.[4] The price will be updated every week and importers can buy as much as they wish at this price. They will be obliged, at the end of each quarter, to hold a stock of permits equal to at least 80% of the value they will have to turn in to cover the imports they have made so far in the reporting year. 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 80% will be calculated according to benchmark values, but if importers end the year with excess amounts because their imports are 'cleaner' than the benchmark, 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 is also achieved if the importers and domestic producers buy their permits in the same market. However, the two approaches have different implications in other dimensions, and we argue that the combined market is the preferable one.

Before exploring this, we note that the UK 'is minded' to use a slightly different structure from the EU for its CBAM. Rather than sell certificates to importers, its consultation document proposes, *inter alia*, a levy on imports paid at the border set by reference to the mean UK ETS carbon 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. Importers play no role in the determination of the carbon price for imports, merely accepting the domestic price and being able to 'buy' as many permits as they wish at that price.

Our argument for a combined market for ETS and CBAM permits is that a combined market 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 provides 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, 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

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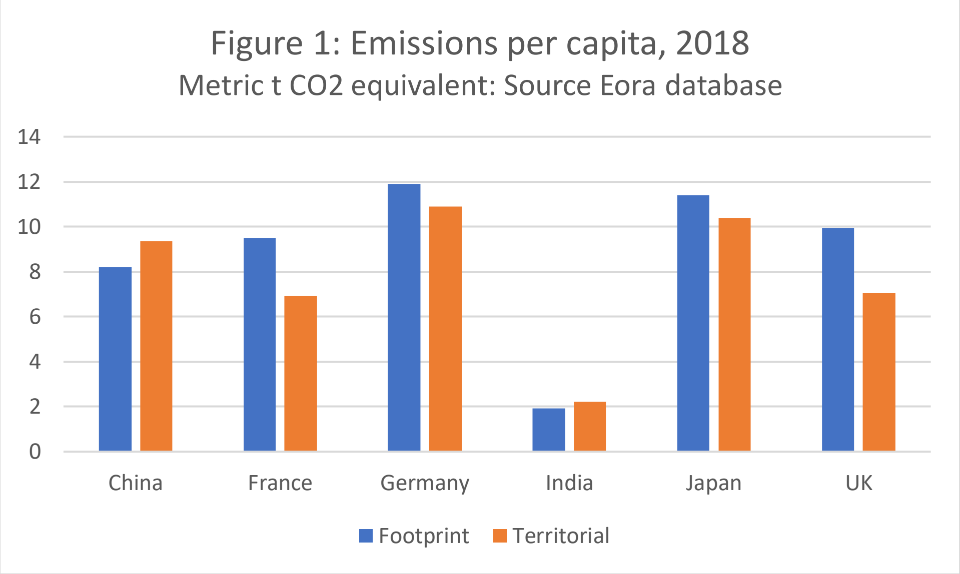
[3] There is one large caveat to the description in this paragraph. At present, to alleviate carbon leakage, the authorities issue free allowances of emissions permits to large emitters who are exposed to international trade. This removes some of the pressure, even if not the incentive, to abate emissions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

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

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: 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, they could directly determine the level of emissions for consumption by their residents. If one has full information about a static and perfectly competitive situation 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 shocks and, as a corollary, when there is imperfect competition or uncertainty.[5]

If one accepts our 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, has the current system been set up as it has. We would speculate that the current set-up is a product of a particular sequence of events. Emissions were originally seen as a production issue and policy and

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[5] 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).

international negotiations focused on national targets to limit them. A natural instrument for limiting national territorial emissions was a cap-and-trade system, which the EU introduced from 2005 – its Emissions Trading Scheme (ETS). 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.

The rest of this paper comprises a simple diagrammatic exposition of the basic idea, a simple (but fuller) economic model to show the outcome in more general circumstances, some simulation of the latter and some brief concluding comments.

1 The simplest model

Figure 2 shows how the ETS and CBAM permit markets for carbon are linked in the EU-style proposal, ignoring all the complications about free allowances, the timing of purchases, etc. The domestic demand for carbon permits is given by the red line D_E (demand is responsive to price) and the cap on permits by the black vertical line labelled 'cap' (unresponsive to price), which we also denote as C_0^E. The price of permits is determined in this market and is then transferred to the CBAM permit market (we assume, perfectly). Given the demand for carbon among potential producers of imports (D_I), demand for carbon settles at C_0^I. We assume that the mechanism through which carbon demand adjusts to price includes the substitution of other inputs (e.g. labour) for carbon given existing technology and the effects of changes in the product mixes within domestic output and imports.

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

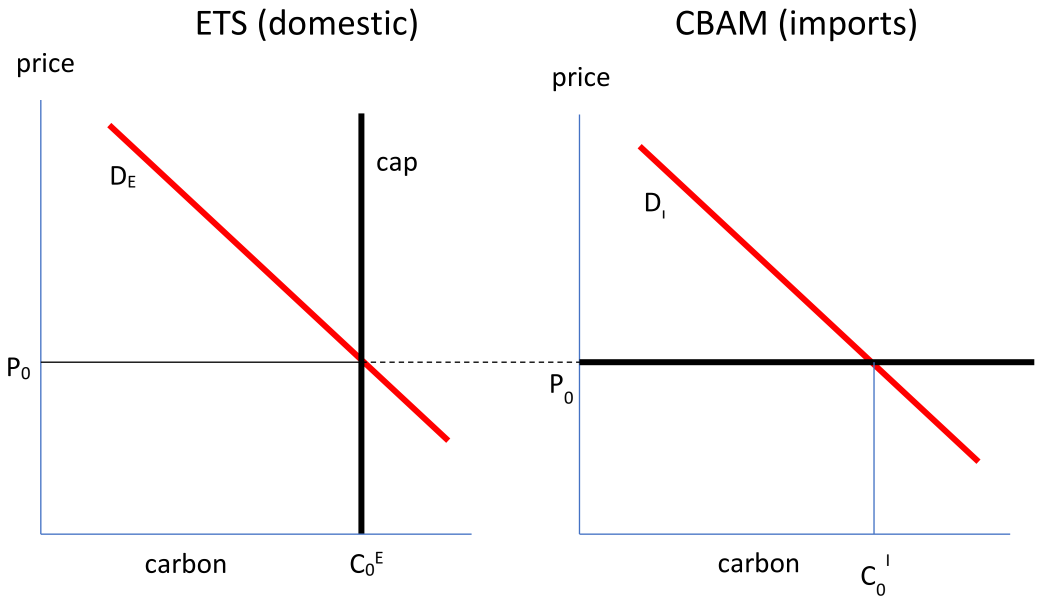
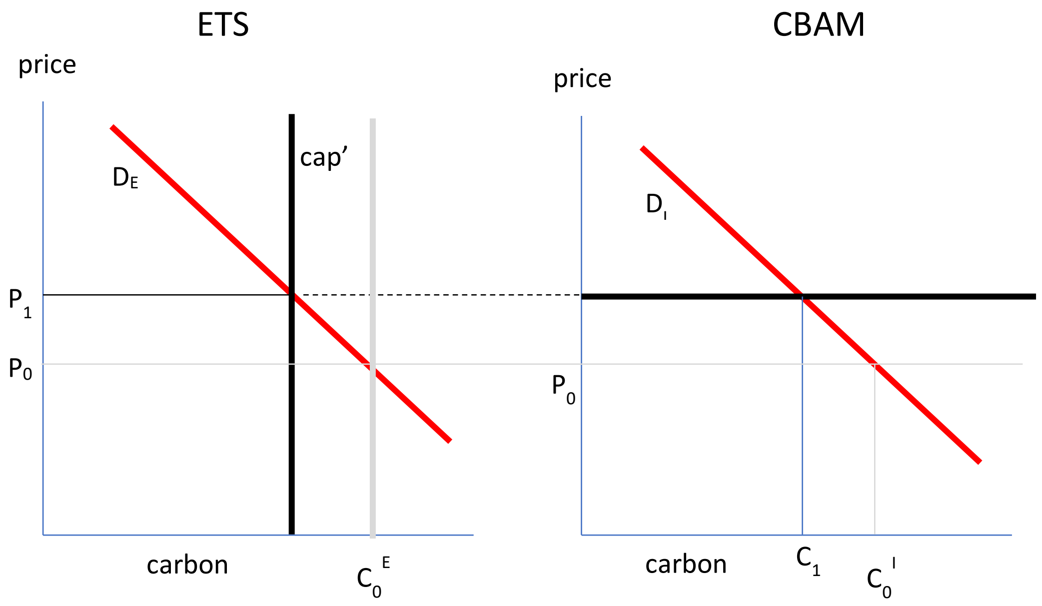


Figure 3 now asks what happens when the authorities reduce the carbon cap within the ETS to cap'. The curves bear the same interpretation as the old curves from Figure 2, which are kept in grey. The story – exactly as one would wish – is that as the cap tightens, the price of ETS permits rises and as this is transferred to the CBAM market, carbon use in imports declines as well. In this figure, the two reductions look roughly the same, but there is no guarantee that this is the case because the demand for carbon 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 carbon is the same in the two markets – there is no discrimination.

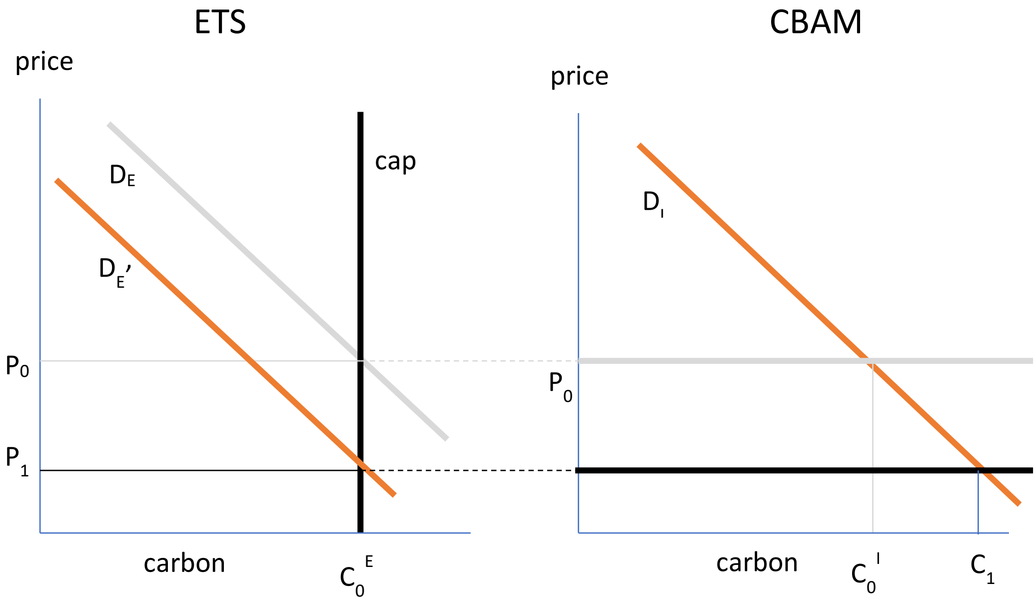
Figure 3: A reduced cap in the ETS



Now consider

Figure 4 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 less carbon. That implies that at any given carbon price the demand for carbon is reduced – it shifts from D_E to D_E' in the left-hand panel. The price of carbon falls to p_1, but usage does not decline because the cap is fixed. When the new price is transferred to the market for imports, carbon use increases to C_1 and the technical progress has resulted in carbon leakage and increased global carbon use! In this case, transferring information by price alone fails the simple climate change test. To prevent this, the authority would have to reduce its cap corresponding to the degree of technical progress to return the domestic carbon price to the original level.

Figure 4: Improvements in EU/UK energy efficiency



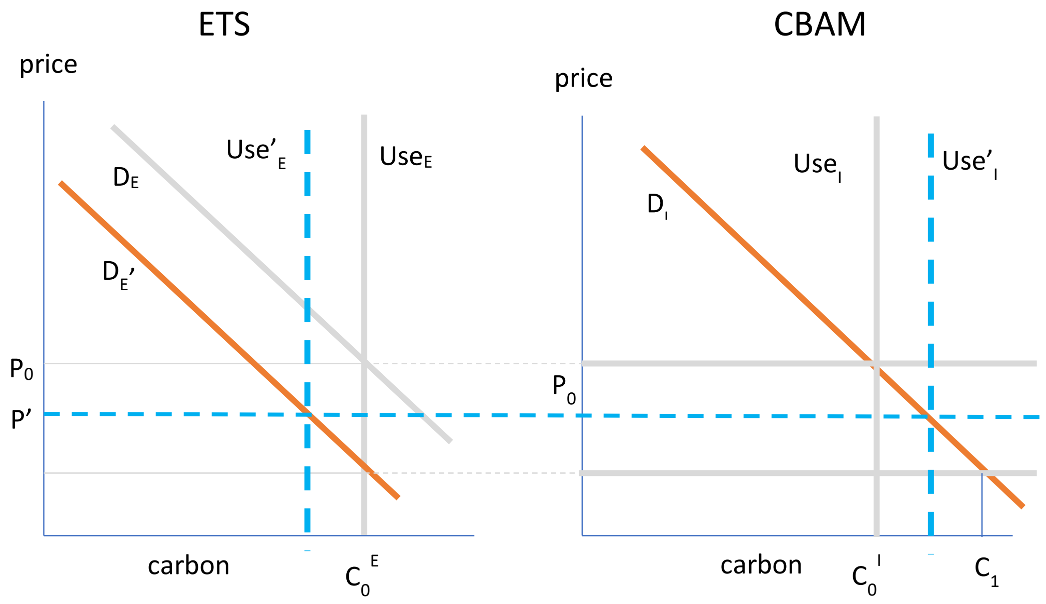
The example in the previous paragraph is a specific one, and it is possible that when technical progress occurs in the EU, it also occurs abroad or that it encourages some sectors/activities to relocate back to the EU. Both of these cases would imply that demand for emissions for imports declines along with domestic demand, and hence both would reduce the leakage relative to that described. However, equally we should recognise that if dirtier sectors relocate 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.

The alternative is to combine the markets for ETS permits and CBAM permit markets. This is explored in Figure 5. 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 EU CBAM, but in so doing would be much more coherent with the long-term objective of net-zero. There would be one cap for all goods consumed, 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 25 we assume that a joint cap were set at the sum ($C_0^E + C_0^I$) and that the equilibrium depicted in the figure showed the outcome of the market process (it would have come about by a different mechanism than we assumed in Figure 2: now, domestic producers could vary their maximum carbon usage as long as they could outbid import producers for the permits). Now we assume the same technical progress shock as we had in

Figure 4. Both import producers and domestic producers would be competing for the given (summed) number of permits and the new equilibrium would settle at something like that in Figure 5. The starting allocation of carbon is labelled as Use_E and Use_I domestically and abroad respectively and after the technical change domestic producers would need less of the total allocation and import producers would be able to take more – say Use_E' and Use_I' respectively, but by construction, the sum of Use_E' and Use_I' would equal the sum of Use_E and Use_I. The price (determined in the combined market with the two demand structures and the overall cap) would be something like p’. With the combined market, there is still leakage – emissions abroad still increase – but there is no global increase in emissions.

Figure 5: Improved energy efficiency with combined market for the ETS and CBAM permits



We have treated the technical progress in this example as manna from heaven, 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.[6] 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.

A further complication is that in the diagrams we have proceeded as if the demands for emissions in domestic and imported goods were entirely independent of each other, but given that they are demanded by the same (UK) consumers, there are likely to be interactions. It is difficult to represent that in this simplest case, but the theoretical model to which we now turn takes it into account.

2 A more formal model

The policy experiment we are examining in this section assumes that the EU (UK) 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 ways of organising the CBAM: one, which we label CBAM, 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 week. 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 (UK). 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.

One dimension of the policy that is undecided in the EU (let alone the UK) is whether the cost of permits will be rebated on exports. If it is, the ETS+CBAM becomes a charge solely on home consumption, whereas if it is not, we are left with a hybrid system charging both home consumption and the consumption of home goods abroad. We model both possibilities.

There are two countries, home and foreign, that can differ in size. There is a polluting good which is differentiated by origin, and consumers are willing to consume both the domestic and foreign variety. The production of these products uses labour and emissions. Then there is a green good which is separable in utility from the polluting product, is freely traded internationally and produced in both countries using labour as the only factor of production. 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 main assumptions of the model are (i) Cobb-Douglas first-tier utility between polluting and non-polluting good; (ii) the non-polluting good uses only labour, which is the numeraire (no income effects); (iii) perfect competition; and (iv) no uncertainty.

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[6] The combined market also hands a smaller unrequited benefit to foreign competitors than does the CBAM which conceivably might also affect innovation incentives.

There are no assumptions for the production function nor the second-tier utility function aggregating home and foreign polluting 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.

The ETS imposes a cap on the total production of emissions in the home production, but no constraint on the foreign market. This means that the production cost of home producers depends on the price of emissions, independent of whether the output is sold in the domestic or foreign market. On the other hand, the foreign producer pays a price for emissions only if it exports, but not for domestic sales. This is because the foreign market does not put a cap on emissions.

In practice, we can model this as having two foreign producers – one producing only for home, and one for both home and exports – or a single producer with two separate products – one for home, one for exports. While the final foreign products can be the same good, they differ in the cost function as the exported product has to pay a tax on pollution.

2.1 Production

The production of the green good X involves only labour and the production function is $X_i = L^X/\varphi_i^X$, 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 polluting good q is $q_i = A_i f_i(L_i, E_i, A_i^E)$ which combines labour L and emissions E_i , together with carbon efficiency (output per unit of carbon input) 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 TFP (with separability in TFP). Then we have:

$$\begin{cases} E_i^d = E_i^d(q_i, p^E, A_i^E)A_i^{-1} \\ L_i^d = L_i^d(q_i, p^E, A_i^E)A_i^{-1} \end{cases} \tag{1}$$

Totally differentiate the demand for emissions to get:

$$\widehat{E_i^d} = \epsilon_i^d \widehat{q_i} + \epsilon_i^{p^E} \widehat{p^E} + \epsilon_i^{A^E} \hat{A}_i^E \ - \hat{A}_i \tag{2}$$

where the ϵs are the elasticities of the demand for emissions, and we have $\epsilon_i^{p^E} < 0$ and $\epsilon_i^{A^E} < 0$. Similarly, the marginal cost will be a function of the input prices p^E and $w_i = \varphi_i^X$. Because labour productivity is constant, there are no income effects. Moreover, in perfect competition, the price equals the marginal cost, so we have an expression for the output price of the type $p_i = p_i(p^E, A_i^E)A_i^{-1}$. Total differentiating the price function to get:

$$\hat{p}_i = \sigma_i \widehat{p^E} + \zeta_i \hat{A}_i^E - \hat{A}_i \tag{3}$$

where the σ and ζ are the elasticities of the output price with respect to the emission price and emission efficiency, respectively. Increasing emission efficiency reduces the output price hence $\zeta < 0$. For international trade we add iceberg transport costs $\tau \geq 1$ such that $p_i = p_i(p^E, A_i^E)A_i^{-1}\tau$. Totally differentiating, we get:

$$\hat{p}_{ij} = \sigma_i \widehat{p^E} + \zeta_i \hat{A}_i^E - \hat{A}_i + \hat{\tau} \tag{4}$$

where p_{ij} is the price of the product from *i* in *j*.

2.2 Consumption

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

$$U_i = \left[\left(X_i^{1-\alpha}Q_i^{\alpha}\right), G_i, e(E)\right] \tag{5}$$

The first terms is a Cobb-Douglas index over the consumption of the non-polluting good X and the polluting product $Q = Q(q_H, q_F)$ that combines the home q_H and foreign q_F varieties. G is a nonrival public good provided by the government and paid for by the entirety of the revenues raised from the sales of emission permits.[7] Hence, we have $G = p^E E^s$ where E^s are the total emissions subject to the policy – the amount of emissions paying for permits. Emissions have a negative effect on utility via the nonrival term $e(E)$, which captures the effect of global emissions on consumers utility, and we have $e' < 0$. 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. In changes we have:

$$\hat{U}_i = (1-\alpha)\hat{X}_i + \alpha\hat{Q}_i + \hat{G}_i + e'\hat{E} \tag{6}$$

Where:

$$\hat{Q}_i = \phi_{ii}\hat{q}_{ii} + \phi_{ji}\hat{q}_{ji} \tag{7}$$

Equation (6) is what we will you use to perform welfare calculation.

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}: $q_{ii} = D(Y_i, p_{ii}, p_{ij})$.[8]

Totally differentiate demands to get the demand for home products in the home market:

$$\hat{q}_{HH} = \eta_{HH}^{p_H}\hat{p}_H + \eta_{HH}^{p_F}(\hat{p}_F + \hat{\tau}) \tag{8}$$

and demand for home products in the foreign market:

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

where the ηs are own-price, cross-price and income 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 the 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 the demand for the differentiated good is independent of the level of income.

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

$$\hat{q}_H = \theta_H\hat{q}_{HH} + (1-\theta_H)\hat{q}_{HF} \tag{10}$$

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

2.3 Two policies, one framework

The two policies considered here, namely the CBAM and Combined Markets (CM) policies, differ in terms of direct control over the emissions. The CBAM, including exports from H, directly controls emissions for all production in H. Foreign emissions of output destined to the Home market adjust

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[7] Thus the revenues are fully redistributed to consumers.

[8] 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 $\delta_{i\neq j} = 0$.

only via the price mechanism. In the CM policy (with exports), there is direct control over all of H's emissions as well as F's emissions for exports to H. Under both policies, 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 welfare analysis are the change in the price of emissions and the change in global emissions following a change in the exogenous variables and the policy instrument. A change in global emissions can be expressed as:

$$\hat{E} = s_{HH}\hat{E}_{HH} + s_{HF}\hat{E}_{HF} + s_{FF}\hat{E}_{FF} + s_{FH}\hat{E}_{FH} \tag{11}$$

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. The two policies put different constraints on (11). Given a supply of emission permits E^s, the policies will cover different parts of the global market. If a CBAM controls only the domestic sales of H, we will set $\hat{E}_{HH} = \widehat{E^s}$, leaving the other emission choices free to adjust. If it controls both H's domestic sales and exports, this implies $s^H_{HH}\hat{E}_{HH} + s^H_{HF}\hat{E}_{HF} = \widehat{E^s}$, where s^H_{ij} are the emission shares of the cap, while the combined market (with Home exports) imposes $s^H_{HH}\hat{E}_{HH} + s^H_{HF}\hat{E}_{HF} + s^H_{FH}\hat{E}_{FH} = \widehat{E^s}$.

The next part that we need to derive is the change in the price of emissions given a change in the exogenous variables. As we fixed the wage with the choice of the numeraire, the change in the price of emissions $\widehat{p^E}$ is what determines how consumption of the polluting good, emissions demand and government revenues will change.

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. This is done by equating a change in demand for emissions (2), appropriately weighted depending on whether the policy affects only H's domestic sales, exports or the combined market, to the change in the supply of emission permits $\widehat{E^s}$, using equations (3)-(4) and (8)-(10). Here we present the change in the price of emissions given a change in the cap, $\widehat{E^s}$, and in energy efficiency, $\widehat{A^E}_i$:

$$\widehat{p^E} = \frac{\widehat{E^s_H}}{\varepsilon} - \frac{\tilde{s}_{H}.\left[\epsilon^q_H\left(\theta_H\eta^{p_H}_{HH} + (1-\theta_H)\eta^{p_H}_{HF}\right)\zeta_H + \epsilon^{A^E}_H\right] + (1-\tilde{s}_{H}.)\left(\epsilon^q_F\eta^{p_H}_{FH}\zeta_H\right)}{\varepsilon}\widehat{A^E_H} \\ - \frac{\tilde{s}_{H}.\left[\epsilon^q_H\left(\theta_H\eta^{p_F}_{HH} + (1-\theta_H)\eta^{p_F}_{HF}\right)\zeta_F\right] + (1-\tilde{s}_{H}.)\left(\epsilon^q_F\eta^{p_F}_{FH}\zeta_F + \epsilon^{A^E}_F\right)}{\varepsilon}\widehat{A^E_F} \tag{12}$$

Where $\tilde{s}_{H}.$ represents the share of emissions covered by the policy pursued by the Home country and $(1-\tilde{s}_{H}.)$ is its complement. These shares differ from those in equation (11) because the denominator is total emissions covered by the policy rather than global emissions. We can express $\tilde{s}_{H}.$ as:

$$\tilde{s}_{H}. = \frac{E_{HH} + \mathbb{1}(\text{Exports})E_{HF}}{E_{HH} + \mathbb{1}(\text{Exports})E_{HF} + \mathbb{1}(\text{policy=CM})E_{FH}} \tag{13}$$

Where $\mathbb{1}(\text{Exports})$ equals one if *H*'s exports are covered by the policy and zero otherwise. The indicator $\mathbb{1}(\text{CM})$ equals one if the policy is the Combined Markets and zero for CBAM, so that emission prices respond to imports only under the CM policy. The denominator is total emissions covered by the policy.

The first term on the RHS of equation (12) describes the reaction of the price of emissions to a change in the cap, the second of changes in emission efficiency of H, and the third the effect of a change in the emission efficiency of F. In the Appendix, we derive an extended version of (12) considering also changes in country size and trade costs, hence encompassing changes in all the exogenous variables of the model. Equation (12) is derived by setting changes in size and trade costs to zero.

The effect of the two policies can be computed by tuning some of the parameters in equation (12). As it is presented, equation (12) represents the change in the price of emissions for the CM policy, where both the domestic and foreign production destined to market H are subject to the emission cap. For the sake of compactness, if we are interested in a policy that affects only the domestic sales of country H, but not its exports to F, we can slightly abuse notation and set $\theta_H = 1$ in equation (12). 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 (plus, if allowed, the H's demand for F's products).[9] Under the CBAM 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 (12). The term ε is a function of different elasticities (defined in the Appendix) representing the general equilibrium change in the demand of emissions accounting for the changes in demand for polluting varieties. 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 the CBAM and CM policies. This assumption essentially says that in the demand for the polluting 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.

2.3.1 Change in the CAP

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

$$\widehat{p^E} = \frac{\widehat{E^s}}{\varepsilon(\tilde{s}_{H.} = 1)} \tag{14}$$

given the assumption that ε <0, this implies an increase in the price of emissions. The response will be larger or smaller depending on whether H's exports are covered by the policy. To compute the adjustment of global emissions we need to compute the changes in F's emissions. For F's exports to H the adjustment follows the adjustment of the price of emissions hence we have:

$$\widehat{E^d_{FH}} = \frac{\epsilon_F^q\left(\eta_{FH}^{p_F}\sigma_F + \eta_{FH}^{p_H}\sigma_H\right) + \epsilon_F^{p^E}}{\varepsilon(\tilde{s}_{H.} = 1)}\widehat{E^s} < 0 \tag{15}$$

If 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:

$$\widehat{E^d_{FF}} = \frac{\epsilon_F^q \eta_{FF}^{p_H}\sigma_H}{\varepsilon(\tilde{s}_{H.} = 1)}\widehat{E^s} > 0 \tag{16}$$

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 demand for more emissions.

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

$$\widehat{p^E} = \frac{\widehat{E^s}}{\varepsilon} \tag{17}$$

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[9] Strictly speaking this would mean having no exports. However, for the purpose of the derivation of eq. (12) it is equivalent.

the change in emissions related to F's exports to H are now covered by the policy. If the policy does not apply to H's exports, there is no change in emissions induced by the policy for sales destined to market F. If exports are covered, then we have:

$$\widehat{E^d_{FF}} = \frac{\epsilon^q_F \eta^{p_H}_{FF} \sigma_H}{\varepsilon(\tilde{s}_{H.} = 1)} \widehat{E^s} > 0 \tag{18}$$

Under the CBAM with exports, global emissions change is:

$$\hat{E} = s_{H.}\widehat{E^s} + s_{FF}\frac{\epsilon^q_F \eta^{p_H}_{FF} \sigma_H}{\varepsilon(\tilde{s}_{H.} = 1)}\widehat{E^s} + s_{FH}\frac{\epsilon^q_F\left(\eta^{p_F}_{FH}\sigma_F + \eta^{p_H}_{FH}\sigma_H\right) + \epsilon^{p^E}_F}{\varepsilon(\tilde{s}_{H.} = 1)}\widehat{E^s} \tag{19}$$

While under the CBAM we have:

$$\hat{E} = (s_{H.} + s_{FH})\widehat{E^s} + s_{FF}\frac{\epsilon^q_F \eta^{p_H}_{FF} \sigma_H}{\varepsilon(\tilde{s}_{H.} = 1)}\widehat{E^s} \tag{20}$$

2.3.2 Change in energy efficiency of Home

Consider now an improvement in the energy efficiency of home $\widehat{A^E_H} > 0$ while holding everything else constant. Under the CBAM, the change in the price of emissions is given by:

$$\widehat{p^E} = -\frac{\epsilon^q_H\left(\theta_H\eta^{p_H}_{HH} + (1-\theta_H)\eta^{p_H}_{HF}\right)\zeta_H + \epsilon^{A^E}_H}{\varepsilon(\tilde{s}_{H.} = 1)}\widehat{A^E_H} \tag{21}$$

With our assumption that $\varepsilon < 0$, an efficiency improvement at home decreases the price of emissions if $\left|\epsilon^q_H\left(\theta_H\eta^{p_H}_{HH} + (1-\theta_H)\eta^{p_H}_{HF}\right)\zeta_H\right| < \left|\epsilon^{A^E}_H\right|$. Under the Combined Markets policy, the price change is:

$$\widehat{p^E} = -\frac{\tilde{s}_{H.}\left[\epsilon^q_H\left(\theta_H\eta^{p_H}_{HH} + (1-\theta_H)\eta^{p_H}_{HF}\right)\zeta_H + \epsilon^{A^E}_H\right] + (1-\tilde{s}_{H.})\left(\epsilon^q_F\eta^{p_H}_{FH}\zeta_H\right)}{\varepsilon}\widehat{A^E_H} \tag{22}$$

and it is more likely to be negative than under the CBAM because the term multiplied by $(1-\tilde{s}_{H.})$ is negative, while the term multiplied by $\tilde{s}_H$ is the same as above.

The change in total emissions is zero for the markets covered by the policy. Under CBAM the change in F's emissions for exports to H is:

$$\widehat{E^d_{FH}} = \left[\epsilon^q_F\left(\eta^{p_F}_{FH}\sigma_F + \eta^{p_H}_{FH}\sigma_H\right) + \epsilon^{p^E}_F\right]\widehat{p^E} + \left(\epsilon^q_F\zeta_H\eta^{p_H}_{FH}\right)\widehat{A^E_H} \tag{23}$$

taking $\widehat{p^E}$ as given. The first term is ambiguous as we have seen above. The second term is negative, and the overall effect remain ambiguous.

If H's exports are not covered, the adjustment in emissions destined to market F pass via the change in efficiency. For H's exports to F we have:

$$\widehat{E^d_{HF}} = \epsilon^{A^E}_H\widehat{A^E_H} \tag{24}$$

If Home exports are not covered by the policy, then there is no change in F's domestic emissions related to domestic sales, as there is no change in the price of H's exports to F. If instead Home exports are covered by the policy, we have:

$$\widehat{E^d_{FF}} = \epsilon^q_F\eta^{p_H}_{FF}\left(\sigma_H\widehat{p^E} + \zeta_H\widehat{A^E_H}\right) \tag{25}$$

The change in global emissions under CBAM with *H*'s exports covered is given by:

$$\hat{E} = s_{FH}\left\{\left[\epsilon_F^q\left(\eta_{FH}^{p_H}\sigma_H + \eta_{FH}^{p_F}\sigma_F\right) + \epsilon_F^{p^E}\right]\widehat{p^E} + \left(\epsilon_F^q\zeta_H\eta_{FH}^{p_H}\right)\widehat{A_H^E}\right\} \\ + s_{FF}\epsilon_F^q\eta_{FF}^{p_H}\left(\sigma_H\widehat{p^E} + \zeta_H\widehat{A_H^E}\right) \qquad (26)$$

And for the case in which exports are not covered by the policy:

$$\hat{E} = s_{HF}\epsilon_H^{A^E}\widehat{A_H^E} + s_{FH}\left\{\left[\epsilon_F^q\left(\eta_{FH}^{p_H}\sigma_H + \eta_{FH}^{p_F}\sigma_F\right) + \epsilon_F^{p^E}\right]\widehat{p^E} + \left(\epsilon_F^q\zeta_H\eta_{FH}^{p_H}\right)\widehat{A_H^E}\right\} \qquad (27)$$

Under the combined markets with *H*'s exports covered, only *F*'s domestic sales are affected via a competition effect as Home export price changes, while all other emissions are controlled by the policy:

$$\hat{E} = s_{FF}\epsilon_F^q\eta_{FF}^{p_H}\left(\sigma_H\widehat{p^E} + \zeta_H\widehat{A_H^E}\right) \qquad (28)$$

If Home exports are not covered, then we have a change in emissions related to Home exports, but no change in *F*'s domestic sales as the price of Home exports does not respond to the price of emissions:

$$\hat{E} = s_{HF}\epsilon_H^{A^E}\widehat{A_H^E} \qquad (29)$$

3 Numerical exercise

For the simulation exercise we ask what would happen to emission prices and total world emissions given an improvement in the energy efficiency of home producers. The simulations are done under both the CBAM and combined markets policies. We also consider both the cases with and without including Home's exports under the policy. The simulation is based on equation (21) and (22) for the change in the emission price, and equations (23)-(29) for the change in global emissions. In the simulation, we consider the EU27 as the home country and the rest of the world aggregate as the foreign economy. We base the analysis on behavioural parameter values pertaining to the iron and steel sector, which accounts for the lion's share of value of the trade affected by the EU's CBAM.

The values of parameters used in the simulation are summarised in Table 2. Information on the parameters of interest is not always available, and some assumptions need to be made.

We assume a unitary elasticity of emission demand to output ϵ_i^q. For the elasticity of emission demand to the emission price $e_i^{p^E}$, we rely on available estimates from three papers. Wang and Lin (2017) use data from the Iron and Steel sector of China over the period 1985-2011 to estimate input shares functions based on a translog production function. They estimate that the own-price demand elasticity of energy consumption is -0.171. Wang et al. (2021) use data from different Chinese sectors over 1999-2015 to estimate an energy consumption function. For the 'Nonmetal & 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. Finally, Roy et al. (2006) estimate a translog model with data from India and South Korea and find that the own-price elasticity for energy in iron and steel is -1.74. We start with the central value of -0.75 from Wang et al. (2021) and perform sensitivity analysis by setting $e_i^{p^E}$ equal to -0.17 and -1.74.

We set the elasticity of output price to the emission price σ and emission efficiency ζ equal to the energy share in production from the FIGARO input-output tables. These values are 0.045 for the EU (the home country) and 0.047 for ROW (the foreign country). Using shares to measure these parameters essentially means assuming an elasticity of substitution across inputs of one. We perform sensitivity analysis by multiplying the shares by 2 and 0.5.

For the own price elasticity of demand, we assume a value of 0.3 following Winters (1995), while the cross-price elasticity of demand is set at 0.15.

The share of domestic sales θ is computed using data from the FIGARO tables for Basic Metals (CPA 24). These are 0.82 for the EU and 0.98 for ROW.

The (bilateral) shares of world emissions s_{ij} are calculated as the energy content (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 CO2 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 CO2 emission of each technology. We then apportion the CO2 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).

Table 1: 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.

Table 2: Values of parameters used in simulations

Symbol	sign	Description	Value	Source
elasticities				
ϵ_i^q	+	Elasticity of emission demand w.r.t. output	1	Assumption
$e_i^{p^E}$	-	Elasticity of the emission demand w.r.t. emission price	0.17; 0.75; 1.74	Wang and Lin (2017); Wang et al. (2021); Roy et al. (2006)
$e_i^{A^E}$	-	Elasticity of emission demand w.r.t emission efficiency	0.17; 0.75; 1.74	Wang and Lin (2017); Wang et al. (2021); Roy et al. (2006)
σ_i	+	Elasticity of output price w.r.t. emission price	0.045 for the EU; 0.047 for ROW	Energy share in production from FIGARO tables; sensitivity by doubling and halving the estimate
ζ_i	-	Elasticity of output price w.r.t. emission efficiency	0.045 for the EU; 0.047 for ROW	Energy share in production from FIGARO tables;

				sensitivity by doubling and halving the estimate
$\eta_{ij}^{p_i}$	-	Own price elasticity of demand	0.3	Winters (1995)
$\eta_{ij}^{p_j}$	+	Cross price elasticity of demand	0.15	Assumption
shares				
θ_i		Share of domestic sales	0.82 for the EU; 0.98 for ROW	FIGARO tables
s_{ij}		Share of world pollution	EU-EU: 0.068 EU-ROW: 0.0129 ROW-EU: 0.014 ROW-ROW: 0.905	FIGARO tables; sensitivity analysis with data from Lei et al. (2023)

Table 3 reports the baseline results of the numerical exercise. We set the elasticity of emission demand with respect to the emission price and efficiency to -0.75 and used the FIGARO energy share in production to compute σ_i and ζ_i. The shares of world pollution are based on FIGARO tables.

In the experiment that we run, we ask what happens to the emission price and total world emissions in the energy efficiency of the EU increases by 10%. All policy scenarios in Table 3 yield a reduction in the emission price. This is because of a reduction in the demand for emissions of EU producers which are now more energy efficient. When EU exports are covered, both the CBAM and the Combined Market policy yield a reduction in global emissions. However, the CBAM without export rebate points to an *increase* in world emissions following an increase in the energy efficiency of the EU, an unwarranted outcome because the improvement in efficiency drives down the price of permits on the domestic market and this is passed on to foreign producers to such an extent that the increase in their sales outweighs any reduction in emissions in the EU. With the combined market, the decline in the permit price and the stimulus to foreign producers are smaller because, as foreign firms seek to sell more to Home, the price of permits is raised (falls by less).

Table 3: Baseline simulation results

Policy	Exports covered?	% change in	
		Emission price	Global emissions
CBAM	Yes	-9.74	-0.02
CBAM	No	-9.74	0.01
Combined Market	Yes	-8.27	-0.11
Combined Market	No	-8.04	-0.10

We perform sensitivity analysis around some of the parameter values, examining all combinations of the three parameters we consider varying – viz. the initial shares of world pollution, the elasticity of emission demand w.r.t. the emission price (and energy efficiency), and the degree of labour and energy substitution in production. The results, reported in Table 4, show that the change in the emission price is always negative. For the CBAM without exports, all the considered parameter values yield an *increase* in global emissions, which can occur also when EU exports are covered by the policy. On the other hand, the Combined Market policy always points to a *reduction* in global emissions.

Table 4: Sensitivity analysis

Policy	Exports covered?	% change in emission price				% change in global emissions			
		mean	min	median	max	mean	min	median	max
CBAM	Yes	-9.42	-9.94	-9.74	-7.82	0.01	-0.10	-0.02	0.13
CBAM	No	-9.42	-9.94	-9.74	-7.82	0.02	0.00	0.02	0.07
Combined Markets	Yes	-7.88	-8.43	-8.04	-6.52	-0.11	-0.11	-0.11	-0.10
Combined Markets	No	-7.64	-8.20	-7.80	-6.32	-0.10	-0.22	-0.09	-0.02

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 then generally 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 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.'[10] 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, a market stability reserve could be used to stabilise prices.[11] Market interference is always a concern, but the argument implies that this is much greater when importers are concerned than when only domestic producers are concerned. The ETS market has market stability arrangements, and these can apply equally well to a larger market including importers. 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

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[10] Paragraph 3 of Committee on Economic and Monetary Affairs opinion in European Parliament (2021)

[11]

permits. It implies that a CBAM-style system is going to seriously limit the number of agents that can actually import, the sort of restriction that development economists have long recognised as one of the most restrictive import barriers there is, e.g. Yeats (1978). Garicano suggests it can also be managed by limiting importers’ purchases of permits 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 this purpose, we can see no additional problem with having a combined market for permits. Also, it is not clear whether imports are more volatile than domestic output (and this is, anyway, just a matter of timing, which the reserve can cope with) and 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 entirely 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/UK aggregate emissions from the consumption of goods is a solely EU/UK objective and involves no more pain for foreign producers that does imposing a border levy.

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.

The UK has yet to determine its approach to the marketing of CBAM permits and we would advocate adopting a combined market. However, if the EU persists with its existing model of separate markets, our advice to the UK Government would be to adopt that model. The arguments for aligning the UK to the EU ETS and CBAM are legion – see, for example, Lydgate et al (2022) – and would almost certainly outweigh those described here. And in that event, the UK should press the EU to move to a combined model. This has actually already been acknowledged by Garicano (2021) as a possible step after the current model has become well established.

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6 Appendix

Here we show how to derive the change in the price of emissions given a change in one of the following exogenous variables: the emission cap; the energy efficiency of domestic producers; the energy efficiency of foreign producers.

The change in emissions demand taking the price of emissions as exogenous, and holding fixed market sizes, total factor productivity and labour efficiency, is given by:

$$\widehat{E_\iota^d} = \epsilon_i^q \widehat{q_\iota} + \epsilon_i^{p^E} \widehat{p^E} + \epsilon_i^{A^E} \widehat{A_\iota^E} \tag{30}$$

And the changes in the other relevant variables are:

$$\begin{cases} \widehat{p_\iota} = \sigma_i \widehat{p^E} + \zeta_i \widehat{A_\iota^E} \\ \widehat{p_J} = \sigma_j \widehat{p^E} + \zeta_j \widehat{A_J^E} \\ \widehat{q_\iota} = \theta_i \widehat{q_{\iota\iota}} + (1-\theta_i)\widehat{q_{\iota J}} \\ \widehat{q_{\iota\iota}} = \eta_{ii}^{p_i}\widehat{p_\iota} + \eta_{ii}^{p_j}\left(\widehat{p_J} + \hat{\tau}\right) \\ \widehat{q_{\iota J}} = \eta_{ij}^{p_j}\widehat{p_J} + \eta_{ij}^{p_i}\left(\widehat{p_\iota} + \widehat{\tau_{\iota J}}\right) \end{cases}$$

Using the equations above together with (30), the change in emission demand is:

$$\begin{aligned} \widehat{E_\iota^d} = & \left\{\epsilon_i^q \left[\theta_i\left(\eta_{ii}^{p_i}\sigma_i + \eta_{ii}^{p_j}\sigma_j\right) + (1-\theta_i)\left(\eta_{ij}^{p_j}\sigma_j + \eta_{ij}^{p_i}\sigma_i\right)\right] + \epsilon_i^{p^E}\right\}\widehat{p^E} \\ & + \left[\epsilon_i^{A^E} + \epsilon_i^q\zeta_i\left(\theta_i\eta_{ii}^{p_i} + (1-\theta_i)\eta_{ij}^{p_i}\right)\right]\widehat{A_\iota^E} + \left[\epsilon_i^q\zeta_j\left(\theta_i\eta_{ii}^{p_j} + (1-\theta_i)\eta_{ij}^{p_j}\right)\right]\widehat{A_J^E} \end{aligned}$$

Finally, set the change in the emission demand $\widehat{E_\iota^d}$ equal to the change in emission supply $\widehat{E_H^S}$ (the cap) to find the change in the price of emissions:

$$\begin{aligned} \widehat{p^E} = & \frac{\widehat{E_H^S}}{\varepsilon} + \frac{\tilde{s}_{H\cdot}\left[\epsilon_H^q\left(\theta_H\eta_{HH}^{p_H} + (1-\theta_H)\eta_{HF}^{p_H}\right)\zeta_H + \epsilon_H^{A_E}\right] + (1-\tilde{s}_{H\cdot})\left(\epsilon_F^q\eta_{FH}^{p_H}\zeta_H\right)}{\varepsilon}\widehat{A_H^E} \\ & - \frac{\tilde{s}_{H\cdot}\left[\epsilon_H^q\left(\theta_H\eta_{HH}^{p_F} + (1-\theta_H)\eta_{HF}^{p_F}\right)\zeta_F\right] + (1-\tilde{s}_{H\cdot})\left(\epsilon_F^q\eta_{FH}^{p_F}\zeta_F + \epsilon_F^{A_E}\right)}{\varepsilon}\widehat{A_F^E} \end{aligned}$$

Where the denominator is:

$$\begin{aligned} \varepsilon = & \tilde{s}_{H\cdot}\left\{\epsilon_H^q\left[\theta_H\left(\eta_{HH}^{p_H}\sigma_H + \eta_{HH}^{p_F}\sigma_F\right) + (1-\theta_H)\left(\eta_{HF}^{p_F}\sigma_F + \eta_{HF}^{p_H}\sigma_H\right)\right] + \epsilon_H^{p^E}\right\} \\ & + (1-\tilde{s}_{H\cdot})\left[\epsilon_F^q\left(\eta_{FH}^{p_F}\sigma_F + \eta_{FH}^{p_H}\sigma_H\right) + \epsilon_F^{p^E}\right] \end{aligned} \tag{31}$$