UK COMPETITIVENESS AND CARBON PRICING

A report for the Commission for Carbon Competitiveness

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Foreword by the Commission for Carbon Competitiveness

The mission of the Commission for Carbon Competitiveness, since its formation in February 2023, has been to develop practical solutions so the UK can reach net zero without undermining the competitiveness of British industry.

One of the main threats to that competitiveness is the risk of ‘carbon leakage’: domestic companies being adversely impacted by carbon costs, while their less efficient, higher carbon international rivals operate without those same costs. This can lead to domestic production being reduced – or ceasing altogether – with emissions simply happening elsewhere. This is bad for our economy, bad for jobs and bad for our shared global environment.

Our first report, *Fixing the Carbon Leak*, published in July 2023 outlines our support for a well-designed Carbon Border Adjustment Mechanism (CBAM) to mitigate the risks of carbon leakage and we were pleased, therefore, to see the Government commit to a CBAM in December 2023. But the Government’s version falls short of our recommendations, which were supported by almost all UK energy-intensive and other manufacturing industries, so we would argue they need to go further than what has already been announced.

This includes a CBAM that matches the timing of EU CBAM’s own operational implementation in 2026, applies to all manufacturing sectors without exception over time, with a clear pathway for each sector, and addresses exports by exempting them from carbon costs under the UK Emissions Trading Scheme (UK ETS).

Another critical recommendation endorsed in our report was that any increased revenue that HM Treasury receives as a result of a CBAM should be used to significantly reduce or even remove the cost of green levies, including fuel duty, which are contributing to the cost of living for ordinary families.

Understanding the scale of any potential revenue is therefore critical to the design of a UK CBAM. That is why we commissioned Frontier Economics to produce this report.

This ground-breaking piece of work presents a detailed analysis of how much a CBAM could possibly raise for HM Treasury, helping us understand the scale of the opportunity the Government might have to prevent ‘double taxation’ of the same emissions, by cutting fuel duties or green levies to offset some of the cost of living challenges facing people across the UK

The long-term ambition of adopting a CBAM is not to generate revenue; it is an environmental measure that aims to prompt behaviour change in other high emitting countries to adopt their own ambitious carbon prices. But the extent to which that occurs and at what pace will be key factors in the amount raised for the Treasury. Other factors will include products in scope of the CBAM and the exact level of carbon price.

While there are a number of scenarios that could be impacted by international trade dynamics, what this report from Frontier Economics demonstrates is that a CBAM which aligns closely with the Commissioner's recommendations could be a significant revenue stream for HM Treasury, even if that is not its primary purpose – with as much as £3.3 billion being generated per year. That could be the equivalent of £117 for every household or 6p per litre off fuel duty.

Whilst this modelling is not a forecast, it shows the scale of the opportunity, and underpins why the Government needs to ensure these unexpected funds are not simply seen as an economic measure, but will be used to help families across our country with the cost of living.

We look forward to working closely with Ministers as they consider the detail of what a UK CBAM will look like in the coming months.

John Penrose MP
Weston-super-Mare (Chairman)

Arjan Geveke
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Jo Gideon MP
Stoke-on-Trent Central

Stephen Kinnock MP
Aberavon

Executive Summary

Frontier Economics were appointed by the Commission for Carbon Competitiveness, a cross-party and cross-industry group, to examine the impact on UK Government revenue of the imposition of a Carbon Border Adjustment Mechanism (CBAM) that reflects the carbon emission-intensity of certain imported products.

The primary purpose of a CBAM is to equalise the emissions price faced by domestically produced emissions intensive goods and their imported counterparts. This is seen as necessary to address the risk of carbon leakage i.e. the relocation of economic activity from jurisdictions that have more ambitious greenhouse gas reduction targets to ones with less ambitious targets, thus jeopardising the effectiveness of actions against climate change. For many sectors (such as energy intensive industries like steel, chemicals, cement, refining and ceramics) ensuring such a level-playing field is an important element of maintaining fair competition.

As a secondary effect it can generate revenue for governments.

<u>Approach to modelling</u>

A CBAM seeks to compensate for the difference between domestic emissions prices and those prevailing in partners. We calculate the CBAM rate by calculating the difference between domestic and partner emissions prices, and applying this to measures of emissions arising in production in the partners in question. The CBAM rate is thus specific to particular products and particular countries. In order to understand the impact of a CBAM on trade flows and revenue earned, we use a global trade model. Our model, described in detail in the main report, reflects the fact that trade between countries is proportional to their size and inversely proportional to trade costs. These costs include physical distance costs, but also policy measures such as tariffs and other measures that increase the costs of supplying one market relative to another, and/or relative to the home market. Any particular "shock" to trade (such as the imposition of a CBAM) that affects one or a particular set of sectors (e.g. steel) has further effects because it affects the allocation for resources across all sectors (e.g. cost of products that use steel as an input). Sectors favoured by a policy will typically expand, while others will contract. The model captures these changes in flows until a new equilibrium is reached. The model is comparative static in nature: that is, it measures the differences between a state of the world with the policy shock versus one without that shock. The estimates are therefore "what-if" simulations, not forecasts.

The revenue raised by the UK government depends on a number of factors: the coverage of the CBAM (more or fewer sectors may be covered); whether other countries impose carbon prices similar to those in the UK; and the speed of adjustment in the affected sectors. For a given sectoral coverage, the more similar carbon prices are similar elsewhere to those in the UK, the lower the revenue. The faster the adjustment to low-carbon production, the lower the revenue. In both cases (higher overseas carbon prices and faster adjustment to low carbon production) competitiveness is then preserved because producers in other countries face similar costs to those in the UK.

The table below summarises revenues across a range of scenarios that reflect different assumptions about the factors described above.

Scenario	Revenue, millions of pounds	Assumptions
1	342-538	UK emissions price at $90 per tonne, EU and Switzerland apply same emissions price as UK, Canada, Japan, New Zealand, South Korea apply 75% of UK price, and China 50%. Narrow product coverage.
2	1,233-1,749	As above but with wider product coverage
3	302-543	UK emissions price at $135 per tonne. Emissions pricing more widespread than in scenarios 1-2. EU, EFTA, S'pore same emissions price as UK; OECD countries apply 75% of UK price, China, Argentina and Brazil apply 50%; Russia 25%, R.O.W applies 10 %. Narrow product coverage
4	1,226-1,870	As above but wider product coverage
5	582-1,028	UK and EU apply an emissions price of $135 per tonne, and treat all other partners as having zero emissions price. Narrow product coverage
6	1,973-3,337	As above but wider product coverage
7	1,431-2,000	UK applies emissions price of $135 per tonne and treats all partners, including EU, as having zero emissions price. EU does the same to the UK. Narrow product coverage
8	4,789-6,843	As above by wider product coverage

Note: lower bound reflects immediate adjustment in trade and production, and upper bound reflects no adjustment at all i.e. the CBAM is levied on trade as it is.

Looking at total UK trade, the CBAM reduces the exposure of covered sectors to international trade, while at the same time reducing exports in non-CBAM sectors (e.g. in services) and increasing imports in these sectors. The CBAM reduces both UK imports and exports because it acts as a tax on imports which also feeds through to exports.

The CBAM is intended to have two “legs”: an import leg which imposes emissions prices on imports, and an export leg that shields or exempts exports from domestic emissions prices, so that they are not placed at a disadvantage on global markets. CBAM proposals, and this modelling, focus only on the import leg.

Discussion on solutions to the export leg have so far been inconclusive, notably in the EU which has already begun the implementation of the import leg. This is largely due to uncertainties about the appropriate administrative design..

The modelling in this report suggests ways in which the export solution might play out. First, in the absence of an export solution, the effects of emissions pricing in the UK would be to reduce sales of emissions intensive exports on global markets. The substitution effects discussed in this report also mean that exports of non-emissions intensive exports, such as services, could increase (as resources are reallocated to them). The export solution would reverse these effects. The main unknown is the reactions of partners to an export solution e.g. through the imposition of duties.

Background

- Frontier Economics were appointed by the Commission for Carbon Competitiveness to examine the impact on UK government revenue of the imposition of a Carbon Border Adjustment Mechanism (CBAM) to reflect the carbon emissions-intensity of imports.
- The EU began the implementation of its version of the CBAM on a transitional basis on 1 October 2023, and is aiming for full implementation by 1 January 2026. The UK Government undertook a consultation from 30 March to 22 June 2023 on the development of a UK version of the CBAM.[1]
- The purpose of a CBAM is to equalise the emissions price faced by domestically produced emissions intensive goods and their imported counterparts, notably energy intensive manufactured goods such as steel, cement and related intermediate products. Specifically, it does this by applying the domestic price of emissions on the emissions resulting from the production of the imported good, in the same way as it applies this price to domestic goods.
- The CBAM in principle also deals with exports. The idea is that UK exports of products covered by the CBAM would be rebated or exonerated the cost associated with domestic emissions pricing, so this does not disadvantage exports in global markets subject to low or no emissions price. To date, neither the UK nor the EU has developed specific plans for the implementation of an export solution for the CBAM; the UK Government has yet to respond to their 2023 consultation, however, that tested stakeholder views on this topic.
- The primary reason advanced for the CBAM is to deal with the risk of "carbon leakage". That is the risk that jurisdictions such as the UK, that are using emissions pricing as part of its commitments to move rapidly to net zero, would see a relocation or diversion of economic activity to jurisdictions with less ambitious emissions reduction targets and that have no explicit mechanism for pricing emissions. Carbon leakage would undermine global progress to net zero, since it would mean that global emissions are not reduced as fast as they would otherwise. It would also leave more ambitious jurisdictions with the costs associated with their climate targets, while also facing an uneven playing field globally in emissions-intensive sectors. This could in turn undermine support for ambitious action on climate change because of concerns about "unfair" competition.
- The imposition of a CBAM on imports is likely to have two main effects. The first is that it will likely change patterns of trade: it seeks to alter the competitiveness of imports from different countries based on their carbon prices; it alters the competitiveness of goods covered by the CBAM relative to those that are not; and it alters the competitiveness of imported goods relative to domestically produced goods. These three effects lie at the heart of tackling the risk of carbon leakage.
- Secondly, the CBAM will also generate revenue as long as imports continue in relevant sectors from countries that have zero or lower carbon prices than the UK, and that are

1 Department for Energy Security and Net Zero and HM Treasury (2023), *Addressing Carbon Leakage Risk to Support Decarbonisation – A consultation on strategic goals, policy options and implementation considerations*.

therefore subject to the CBAM. This revenue-raising aspect is one of the advantages of the CBAM over other methods of dealing with the risk of carbon leakage, notably the free allocation of emissions permits to emissions intensive trade-exposed sectors.

- This work focuses on modelling the revenue that could be raised, although to do so we have modelled aspects of the competitive dynamics through the effects of the CBAM on international trade.
- We also consider the ways of measuring the impacts of possible future solutions for UK exports under the CBAM.

Approach

General framework and principles

A Carbon Border Adjustment Mechanism (CBAM) is similar to – but more complex than – other border adjustments measures. The principle of a “border adjustment” is taken from the operation of indirect taxes on consumption, such as VAT. In these cases, it is relatively straightforward to apply the mechanism. If a VAT of 20% is levied in a jurisdiction, then that rate is also levied at the point of sale on imported items. That ensures that imported items are not at a cost advantage relative to domestically produced goods and services, and also ensures that HMRC can collect VAT revenue from imports. Similarly, exports leaving the country are exempted from VAT, on the understanding that they would be subject to applicable indirect taxes in the market of destination.

The mechanism is not so straightforward to apply in the case of an emissions price. First, the emissions price is specified in monetary terms (pounds per tonne of emissions), not in *ad valorem* terms. Secondly, the price applies to production, and specifically to the emissions that arise from production in foreign jurisdictions. Thirdly, it applies to the difference between the emissions price charged in the EU and the emissions price that is applied in the jurisdiction of origin.

The key first step in modelling the effects of the CBAM is therefore to work out the *ad valorem* rates that would be applicable to a particular import, from a particular country of origin, based on differentials in emissions prices and on the embodied emissions intensity of the imports. To do this, it is necessary to have information about prevailing emissions prices in the UK and its trade partners; the product coverage of the CBAM; and the emissions embodied in these products. All of these parameters are subject to variation, across countries and over time. We therefore need to develop CBAM scenarios, which are discussed in greater detail in the next section of this report.

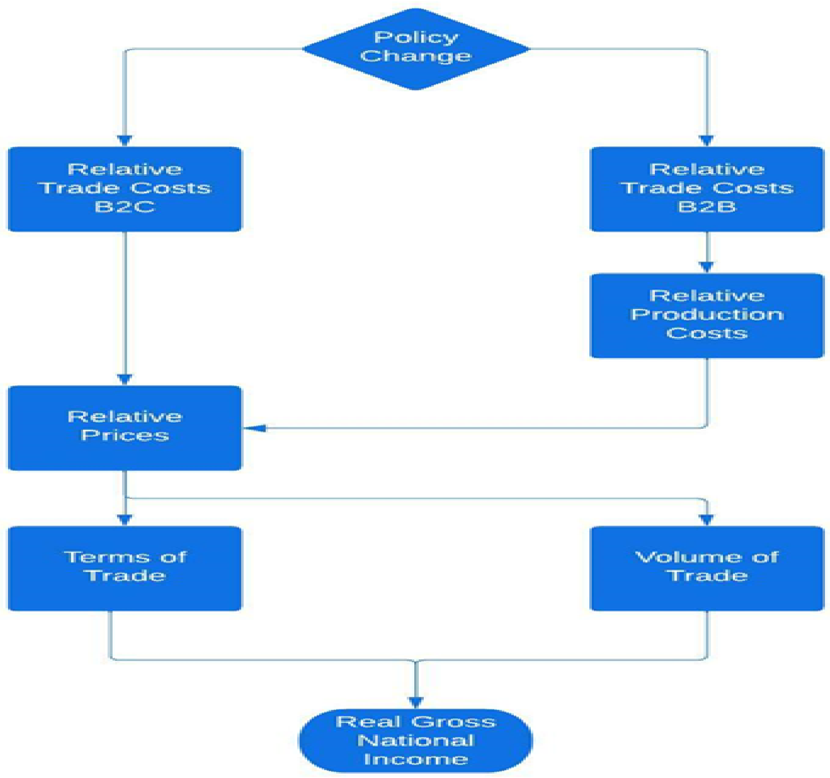
The next step is to estimate the revenue effects of the CBAM, once it has been converted into *ad valorem* rates. In this sense it acts like an import tariff – revenue collected is equal to the *ad valorem* rate multiplied by the value of imports. As with standard import tariffs, the calculation of CBAM revenue effects needs to take into account the extent to which imposing the CBAM leads to changes in trade patterns. Indeed, as already explained, changes to such trade patterns is the point of the CBAM: it seeks to substitute high emissions intensity imports with lower emissions intensity ones, and domestic production for high intensity emissions imports. The greater these substitution effects, i.e. the more successful the CBAM is in addressing its core objective of tackling the risk of carbon leakage, the lower the revenues collected relative to a situation in which there was no change in trade patterns.

To analyse the trade effects of the CBAM, we draw on a well-established modelling framework, known as gravity modelling. Its main elements are described in Box 1, while the technical details of the model are provided in Annex C. In essence, the model allows us to simulate the trade and broader economic effects of different CBAM scenarios, taking into account substitution between countries and sectors, and within these countries between trade and domestic production.

The results of the modelling are simulations, and not forecasts. That is, they are estimates of trade and economic impacts in a world in which a CBAM were applied to a specific range of products (the "counterfactual"), compared to a world without that CBAM ("the baseline"). This approach allows us to develop alternative scenarios for the CBAM "counterfactual" case, which capture different hypotheses or conjectures about the state of the world, and allows us to test the impacts of these alternative states against the baseline.

Gravity Model of Trade

We use a gravity model of trade that is embedded in an overall general equilibrium model. We use the term "gravity" to reflect the proposition that trade between countries is proportional to their size and inversely proportional to trade costs. The costs include physical distance costs, but also policy measures such as tariffs and other measures that increase the costs of supplying one market relative to another, and/or relative to the home market. We use the term "general equilibrium" to capture the fact that sectors are linked between and across countries. A policy measure affecting one or a particular set of sectors has further effects because it affects the allocation of resources across all sectors. Sectors favoured by a policy will typically expand, while others will contract. The model is schematically depicted below.



From the schematic above, it can be readily observed that the key variable that translates the policy change into modelled results is the change in trade costs. This is where the gravity modelling intervenes. The functional specification for the gravity model is given in the Annex C. The intuition is that the imposition of a CBAM *ad valorem* tariff shocks trade costs between any pair of partners. The gravity model measures the effects of these, controlling for trade costs between the countries and the rest of this world (a concept referred to as multilateral resistance), internal trade within countries, the size of the countries, and other factors driving trade costs such as distance and policy sources of trade costs (e.g. tariffs and non-tariff measures).

Scenarios

Assumptions about emissions pricing and product coverage

As already explained, the key first step is to estimate *ad valorem* rates for the CBAM that then can be imposed on trade flows between the UK and partners. This in turn requires making assumptions about: (i) emissions prices in the UK and the magnitude and prevalence of emissions prices in the UK's trade partners and; (ii) product coverage of the CBAM and measures of embodied carbon.

Pricing scenarios

Because the aim of the modelling is to produce simulations, the key requirement is to consider a range of options that could plausibly hold in the medium term. To that end, we base our assumptions on emissions prices on the projections contained in the World Energy Outlook (WEO) of the International Energy Agency. Specifically:

- A lower emissions price scenario for the UK of $90 per tonne of carbon dioxide equivalents (CO_{2e}). This is consistent with stated policies (the "stated policies" case);

- A high emissions price scenario of $135 per tonne of CO_{2e}. This is consistent with pledges for future action (the "pledged policies" case).

We assume that the UK and the EU have the same emissions price under both scenarios. This is consistent with the treaty commitments undertaken in the Trade and Cooperation Agreement (TCA) between the two jurisdictions, notably provisions under Article 392 on cooperation on mitigation matters and "serious consideration" to linking carbon pricing.

In the stated policies case, we assume that only jurisdictions that have emissions pricing arrangements that cover the entirety of their territory (either because of a jurisdiction-wide scheme or a series of regional schemes) have an emissions price. The exact emissions price depends on their reduction commitments (see Annex A for details). The jurisdictions that fall into this category are Canada, China, Japan, New Zealand, South Korea and Switzerland.

Under the pledged policies case we assume more ambitious reduction commitments in the UK and the EU. Regarding the global coverage of emissions pricing, our core assumption is that emissions pricing has been implemented in all major trade partners of the UK and the EU, in response partly to the use of mechanisms such as the CBAM that are designed to incentivise the use of emissions prices. Emissions prices are in line with their pledged greenhouse gas reduction targets (see Annex A for details).

We also consider a secondary variant of the "pledged policies" scenario, in which the UK and the EU are the only jurisdictions to implement emissions pricing. In other jurisdictions, emissions pricing is either not implemented as a means of pursuing reduction targets; or its effect on CBAM goods has been fully offset (e.g., through free permit allocation), meaning that from CBAM purposes, the effective emissions charge on these goods is zero.[2] Finally we consider, as an added modelling sensitivity to this last variant, a scenario in which the UK and the EU treat each other, for the purposes of the CBAM, as not applying an emissions price to their respective exports of covered products.

Product coverage and embodied emissions

The product coverage for the UK CBAM has not yet been settled, although the UK Government's 2023 consultation looked at covering all UK ETS obligated sectors. We focus on two cases:

- Limited range ("narrow"): iron and steel, aluminium, fertilizer, cement.
- Extended range ("wide"): other metals, paper and printing, rubber and plastics, chemicals, other non-metallic mineral products (e.g. glass), coke and refined petroleum products, energy.

Under CBAM arrangements, the differential between the UK emissions price and the trade partner's price would be applied to the embodied emissions in these products. By embodied emissions we mean those that are emitted in the production of these products. Data on these embodied emissions are gathered from use the OECD Trade in Embodied CO_2 (TECO[2]) dataset. This is based on internationally interlinked input-output tables. It enables a complete understanding of inputs of inputs up to an infinite order, fully capturing indirect uses. The emissions that come under the scope of the CBAM are: emissions generated from the production of goods at the level of installations; emissions from the electricity consumed in the production of the goods; and emissions from input material that comes under the CBAM scope.

[2] The situation in which trade partners implement emissions pricing and then offset the effects on exports, which are then subjected to the CBAM in the UK and Europe is similar to the situation with standard indirect taxes e.g. goods produced in Japan or Canada are exempt from indirect taxes when exported, and are subject to UK or EU member state VAT rates following importation.

CBAM scenarios

Based on the assumptions about emissions prices (including pricing behaviour in partners) and product coverage set out above, we can develop a scenario grid as depicted in the figure below.

FIGURE 1 Scenario grid

1. **Scenario 1: Stated policies, narrow sector coverage**	2. **Scenario 2: Stated policies, wide sector coverage**
3. **Scenario 3: Pledged policies, narrow sector coverage**	4. **Scenario 4: Pledged policies, wide sector coverage**
5. **Scenario 5: Maximal CBAM, narrow sector coverage**	6. **Scenario 6: Maximal CBAM, wide sector coverage**
7. Scenario 7: As with 5, but with CBAM also applicable to UK-EU trade	**8. Scenario 8: As with 6, but with CBAM also applicable to UK-EU trade**

Scenarios 1-4 are the core scenarios under consideration. Scenarios 5 and 6 can be considered to be sensitivities around scenarios 3 and 4, in which we change assumptions about the extent to which emission pricing in trade partner jurisdiction applies to exports of CBAM-covered products. Scenarios 7 and 8 are further sensitivities where we relax the assumption that UK-EU trade is not subject to CBAM duties.

The scenarios should be understood as deviations from the baseline situation. The baseline in this case is a world in which the CBAM is not applied in either the EU or the UK. (We also consider an alternative baseline in which the EU applies the CBAM, and the UK does not. See Annex B.).

The scenario specifications help us to compute that the *ad valorem* CBAM rate that will apply to any particular trade flow between a partner and the UK for a particular product.

Assumptions about the speed at which trade and production responds to CBAM

The primary function of the CBAM is to ensure that there is substitution in trade away from producers of goods that are emissions intensive but subject to relatively low or no emissions prices, to producers of like goods that are subject to high emissions pricing. This is required to address the risk of carbon leakage and the perception that emissions-intensive sectors are not competing on a level playing field.

The modelling framework we use measures these patterns and the extent of substitution, and tells us how production and trade has changed under the CBAM scenarios relative to the baseline. As already observed, the modelling framework is a comparative static exercise, in the sense that it shows the outcomes after adjustments have taken place.

The adjustment process itself may take some time and may not be complete. For example, even if the CBAM incentivises domestic production over imports, it may take time to increase capacity because of lags in investment, which can further be affected by broader economic factors. Suppliers may also have fixed term contracts that are difficult to change.

This can have implications for the modelling of revenues. If trade and domestic production respond to the CBAM, then revenues are determined by the *ad valorem* rates applied to post adjustment trade flows. At the other extreme, if there is no adjustment, then CBAM revenues will be those that are obtained by levying the *ad valorem* rates on current trade.

In our modelling we therefore consider sensitivities to the scenarios presented above in which, in the short run, there is no domestic production response, and no substitution to low emissions import sources from and high emissions ones.

Results – revenue raised from CBAM and trade impacts

The overall revenue raised reflects revenues from CBAM, and also from any changes to tariff revenue that arise because of the changes in patterns of trade. The changes in the pattern of trade are discussed in the next section.

Summary of results

The table below summarised the revenue ranges across the eight scenarios. The lower bound represents the case with full adjustment of production and trade; the upper bound with no adjustment.

Scenario	1	2	3	4	5	6	7	8
Revenue, millions of pounds	342-538	1,233-1,749	302-543	1,226-1,870	582-1,028	1,973-3,337	1,431-2,000	4,789-6,843

Based on our four core (1-4) scenarios we estimate that a UK CBAM could raise between £0.3 billion and just over £1.8 billion per year.

The upper bound could increase further depending on assumptions made about the way in which the UK and the EU treat partner country emissions pricing, and assumptions about the extent and speed which UK domestic production and imports from low emissions partners react to the CBAM.

- If trade partners are all treated as applying a zero emissions price on CBAM exports (scenarios 5 and 6) then, revenues could rise to just under £2.0 billion per year
- If in addition, there is assumed to be no UK domestic production response, and no substitution between trade partners in line with emissions intensity, revenue could rise further to around £3.4 billion.
- Finally, if the CBAM also applies to UK-EU trade, then revenues could rise just under £7 billion, if there were no trade or domestic production response.

Starting from a baseline in which the EU imposes a CBAM, but the UK does not, has no material effect on the results presented.

Over time it is likely that we would observe substitution effects from sources that are subject to a high CBAM to ones that are subject to a low CBAM. This is in line with patterns of substitution and trade diversion observed in relation to the imposition of more standard duties on international trade, such as with anti-dumping duties. We may also observe some domestic response. If neither of these effects were to materialise, it would imply that the CBAM had failed to do its job i.e. shore up the competitiveness of domestic industry and strengthen progress internationally towards net zero by dealing with the risk of carbon leakage

Regarding the treatment of partner emissions pricing, the UK (or the EU) may be unwilling to persistently treat partners with an emissions pricing scheme as having no emissions price, given the risks this involves in terms of trade litigation under WTO rules. Countries with a higher degree of ambition on climate change could also pursue arrangements such as "climate clubs", and essentially disapply border adjustment measures between themselves.

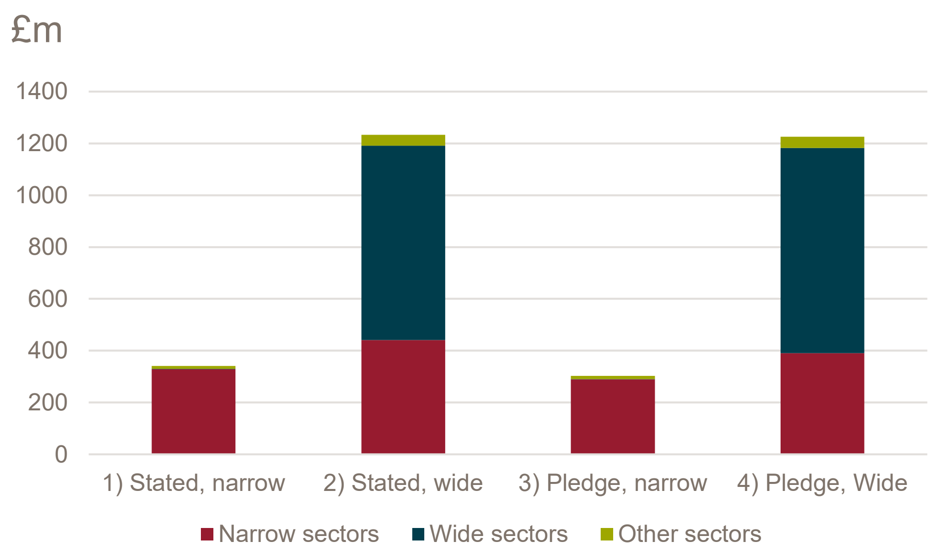
A combination of these influences would tend over time to drive revenues closer to those estimated in the scenarios 1-4.

Tariff revenue impacts – detailed analysis

Tariff revenue impacts – four core scenarios

Figure 2 reports revenue effects for one year for the four core scenarios, and shows the provenance of the revenues.

Figure 2 Trade revenue under four main scenarios (annual)



Source: *[Insert Source here]*
Note: *[Insert Notes]*

The effects of CBAM on exchequer revenue are moderated by the fact that it reduces imports overall, and substitutes trade for domestic production (see the section on trade impacts for a more detailed discussion). Import reductions are most heavily focused on the countries and sectors for which the CBAM rate is highest.

For example, in the case of basic metals in scenario 2, imports fall by 73% from India and 30% from China, corresponding to CBAM rates of 32% and 9% respectively. By contrast, UK-EU trade increases. But as this is CBAM free, this does not generate any revenue. There are also increases in imports in products (e.g. services and crude oil) on which no import tariffs are levied.

The revenue effects are higher when the product coverage is wider, as the taxable base is broader. The revenue effects do not change much between “stated” and “pledged” emissions prices. This is because even though emissions prices in the UK increase, we also assume an increased prevalence of emissions pricing globally, which in turn reduces the differential between the UK and partners, and thus the *ad valorem* CBAM rates applied to imports to the UK.

Tariff revenue impacts – speed of adjustment considerations

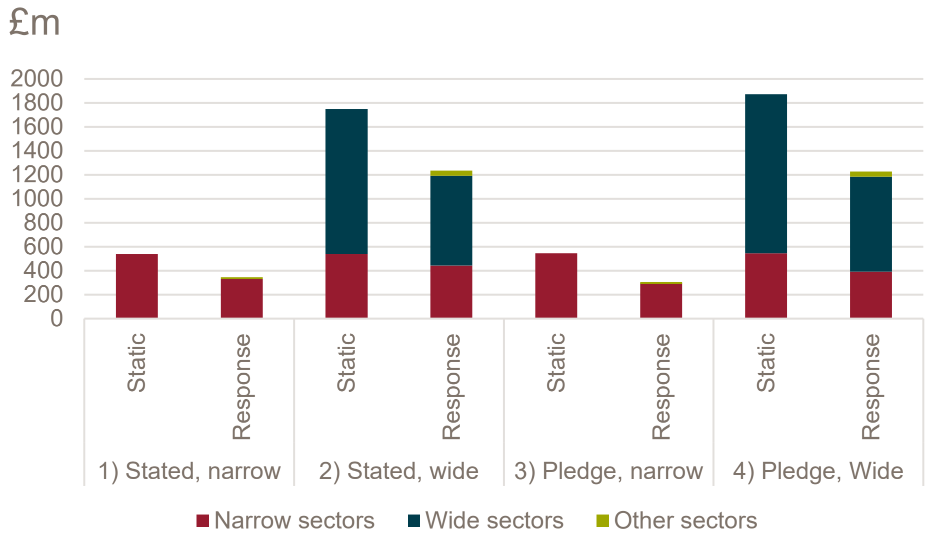
We next consider how these revenue effects may vary based depending on the extent to which trade and production respond to the imposition of the CBAM, and the *ad valorem* rates associated with it. The “static” bars in Figure 3 report the revenue effects in the case that there is no response i.e. if trade patterns remain as they were pre CBAM. In that case, the revenues collected are simply the product of the *ad valorem* rates applied to import values for current trade flows between the UK and partners. The “response” bars reproduce the revenue figures from Figure 2.

We see that the differences are considerable – in the wide product cases, around 40% higher in the event that trade flows remain static. While this points to increased revenue possibilities, at the same time the implication is that the CBAM has not met its primary function of inducing substitution, which it needs to do in order to meet the risk of carbon leakage.

In practice, it is unlikely that a “no response”/ static outcome would provide to be a durable one. Even if UK domestic production in the CBAM sectors prove to be sluggish in response to higher priced imports (e.g. because of uncertainties affecting the investment landscape), we would expect there to be substitution between the trade partners (from high emissions intensity partners to low intensity). There is a substantial body of empirical evidence that suggests that these substitution effects between countries are significant.[3] This would in turn reduce revenues.

[3] See for example, Wang and Hannan (2023), “Trade diversion effects from global trade tensions – Higher than we think”, IMF Working Paper 23/234

Figure 3 Change in tariff revenue – comparison of 'static' and 'response' results for the four main scenarios



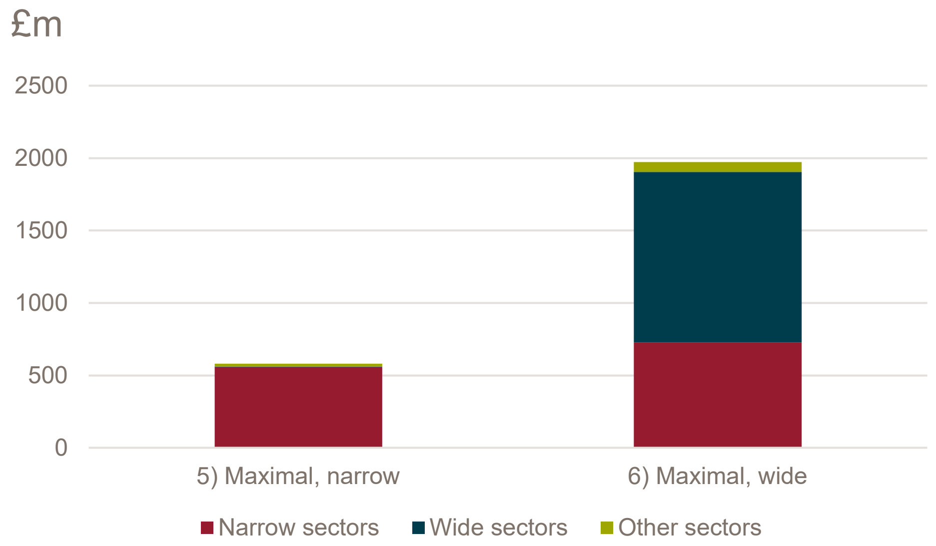
Source: *[Insert Source here]*
Note: *[Insert Notes]*

Tariff revenue impacts – maximal scenarios with no origin credits

Figure 4 reports revenue results for scenarios 5 and 6, i.e. the maximal scenario in which the UK and EU implement emissions prices as per the pledge scenarios, but all partners are treated as if they have not applied an emissions price to their CBAM exports (either because they do not price emissions or have rebated/shielded their CBAM sectors from the domestic emissions price).

Understandably, the results are significantly larger than under scenarios 3 and 4 – by up to 50%. This reflects the higher CBAM rates. At the same time, the impacts on revenue are moderated by substitution towards UK-EU trade (which is CBAM-free) and to UK domestic production.

Figure 4 Change in tariff revenue – maximal scenarios with no origin credits

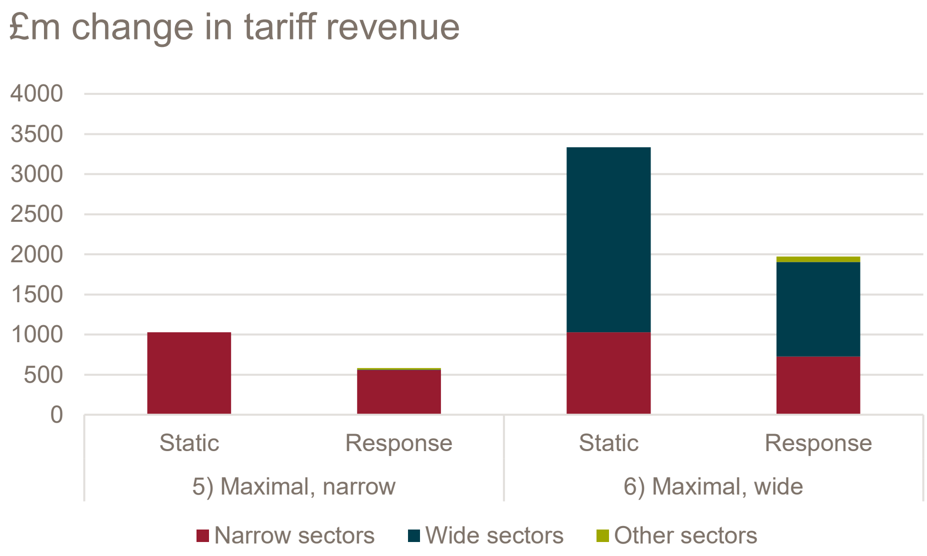


Source: *[Insert Source here]*
Note: *[Insert Notes]*

Adjustment effects under the maximal scenarios

If trade and domestic production are assumed not to respond to the introduction of the CBAM, then revenues would increase (Figure 5). The increase in revenue is again substantial – around 65% in the case of the wide scenarios.

Figure 5 Change in tariff revenue – comparison of 'static' and 'response' results for the maximal scenarios



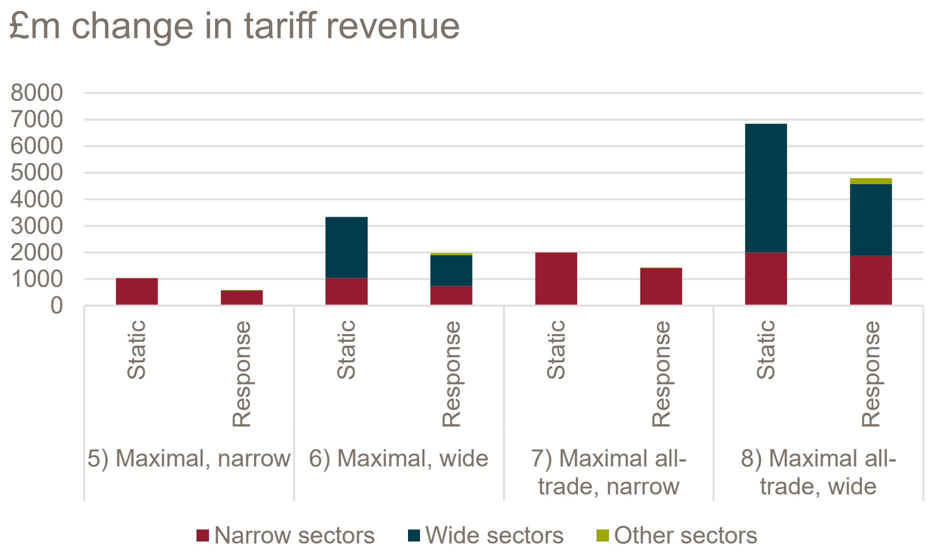
Further sensitivities

As can be seen from the preceding discussion, the extent of effects on revenues (and trade) vary significantly depending on the assumptions made about extent of the CBAMs effects and adjustment. A final case, would be one in which the UK and EU apply the CBAM to each other as well as on all partners (Scenarios 7 and 8). We present these results below in Figure 6, where for the sake of comparison we contrast them with the results for scenarios 5 and 6.

We observe that the results are considerably larger, in the wide product scenario, by a factor of around 2.5. With no trade response, revenues would be just under £7.0 billion. The steep increase reflects the size of the trade between the UK and EU; and specifically, the EU's importance to the UK as source of goods imports.

The magnitude of UK-EU trade explains the level of detail contained in the TCA between the two parties relating to trade in goods, including provisions on emissions pricing. While the TCA falls far short of single market arrangements, it is also substantially deeper than free trade agreements the UK and the EU, respectively, have signed with third parties. For these reasons, we consider them to be more in the vein of illustrative upper revenue bounds.

Figure 6 Change in tariff revenue – comparison of 'static' and 'response' results for the maximal scenarios



Overview of trade and economic impacts

Introduction

This section presents more detail on the impacts of the CBAM on aggregate trade, and on the composition of imports. We also report overall GDP effects. The trade effects underpin the revenue numbers presented in the previous section. They also provide a guide to the effects of the CBAM on competitiveness, and along with the GDP effects, to its overall economic impacts.

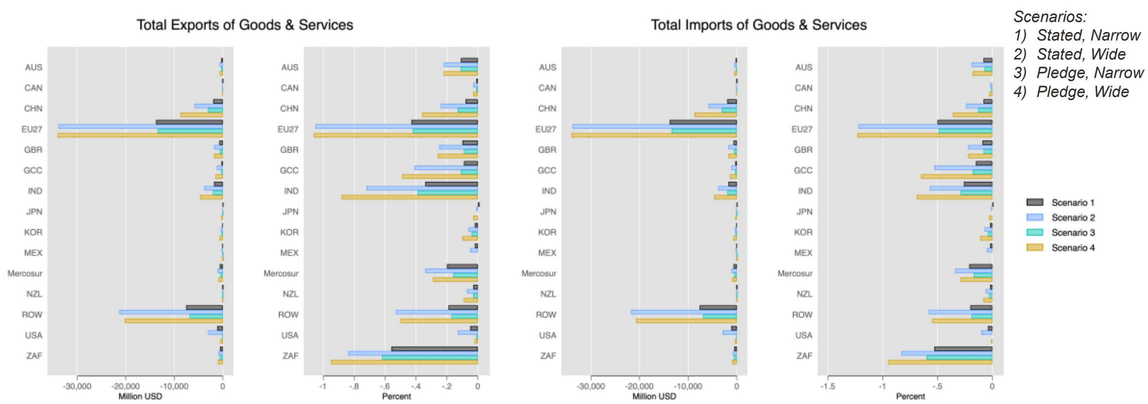
More detailed results, including of *ad valorem* tariff rates under the scenarios, are found in Annex B.

Impacts of the four scenarios

Aggregate trade

In aggregate, the CBAM reduces imports and exports for the two jurisdictions imposing it – the EU and the UK. The effect on exports reflect a property that the CBAM shares with standard tariffs, namely that a tax on imports acts as a tax on exports. This is because it: (i) raises input costs for certain sectors (ii) it increases domestic prices relative to world prices and therefore makes supply for local markets more profitable than for foreign markets.

Figure 7 Impact of CBAM on trade flows by country group under the four core scenarios



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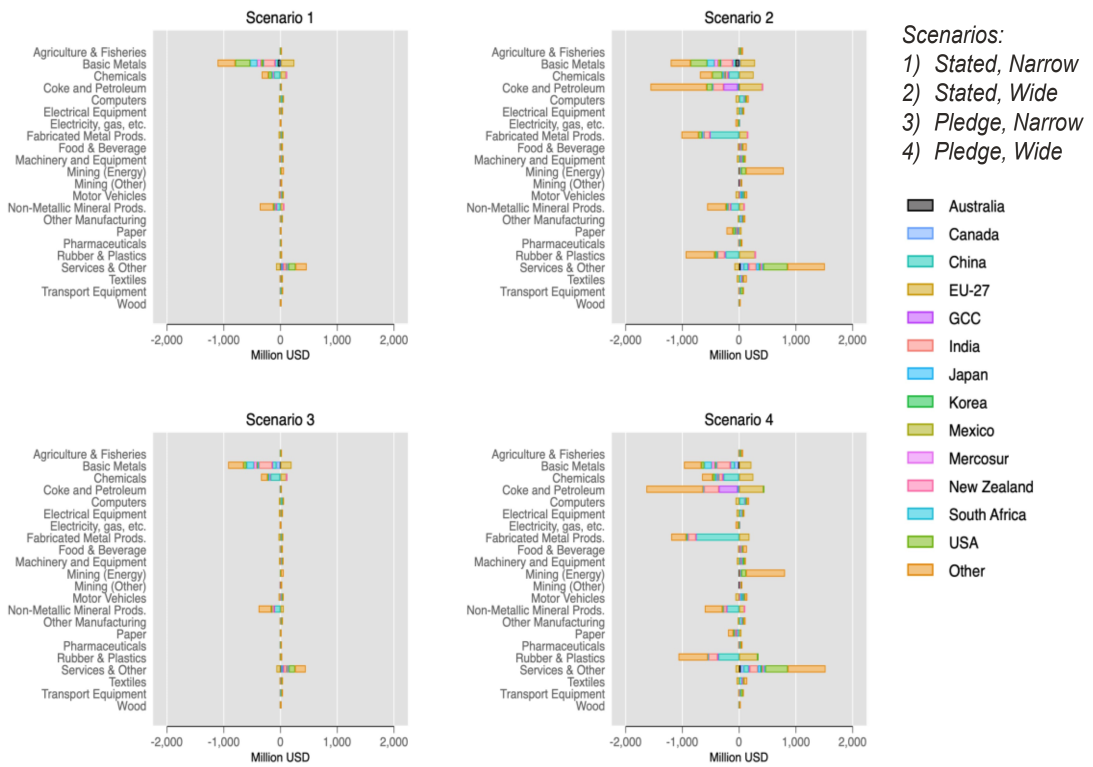
UK trade effects are smaller than for the EU because CBAM sectors make up a smaller share of imports for the UK. CBAM largely covers manufactured inputs/intermediate products, which are less prominent in the UK economy. For example, chemicals, basic metals and non-metallic minerals (the most important CBAM sectors) represents 9% of EU imports but only 5% of UK imports. The 'wide' product range represents 19% of EU imports but only 15% of UK imports.

For scenarios 1-4, the bigger impacts are driven by the scenarios with broader product coverage. Under our modelling, projected emissions prices vary, but so do assumptions about the extent of implementation of emissions prices globally. In the pledged scenarios, UK and EU emissions prices are higher, which would lead to a higher CBAM rates, but more partner countries implement emissions pricing which reduces CBAM.

Sectoral trade effects

Figure 8 reports the effects of the CBAM on the sectoral composition of UK imports, and also reports the origin of these imports.

Figure 8 Impact of CBAM on UK imports by sector under the four main scenarios



In particular, we observe:

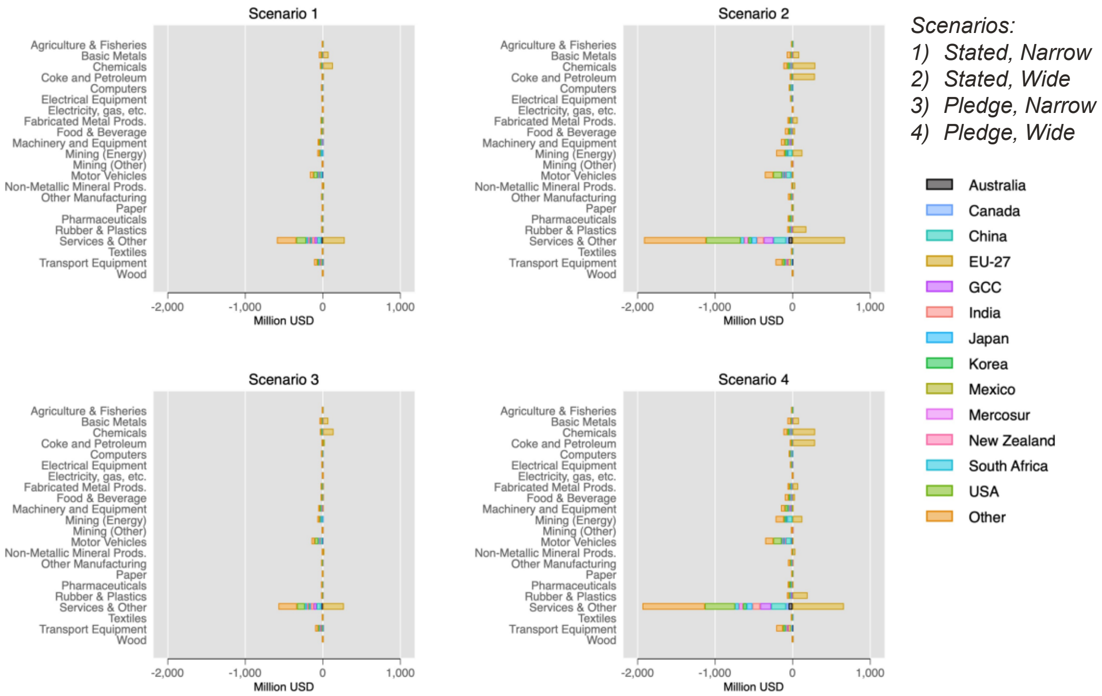
- As expected, there are negative impacts on imports in the CBAM sectors from CBAM-affected partners.

- This is partly offset by increased imports from the EU in the CBAM sectors, since UK and EU trade is “CBAM-free”. The two form a *de facto* carbon club, which is in line with the revealed preferences of negotiators on both sides, as reflected in the TCA. This leads to trade diversion from other sources that are subject to CBAM, a standard result in international trade research.
- We also see substitution into non-CBAM sectors for CBAM-affected countries. For example, the US exports less basic metal to UK, but is now exporting more services, relative to the non-CBAM baseline. Services imports in general increase significantly from all sources, bar the EU, which reflects the fact that there is no increase in duties on EU goods and therefore no impetus for substitution.
- There is also, in the wider scenarios, increased imports of mining and energy products (essentially crude oil) because of increased demand by CBAM-covered sectors within the UK, and (to a lesser extent), positive growth effects.

Figure 9 reports results for UK exports. These suggest an increase in exports in the CBAM sectors to the EU, since UK-EU trade in the products of these sectors is CBAM-free. The extent to which this happens depends on supply side factors, notably the extent to which there is capacity to expand production in these sectors. To the extent there are supply side constrains this, the export response will be more limited.

The UK’s services exports exhibit the strongest drop overall, notwithstanding increases in exports to the EU. This result follows logically from the imposition of the CBAM. In a non-CBAM world, services exports would increase as they are largely low emissions and are sectors in which the UK has a strong comparative advantage. The structure of the CBAM favours non-services sectors, directing resources to them, and also increases the cost inputs to services that comes from the CBAM sectors.

Figure 9 Impact of CBAM on UK exports by sector under the four main scenarios



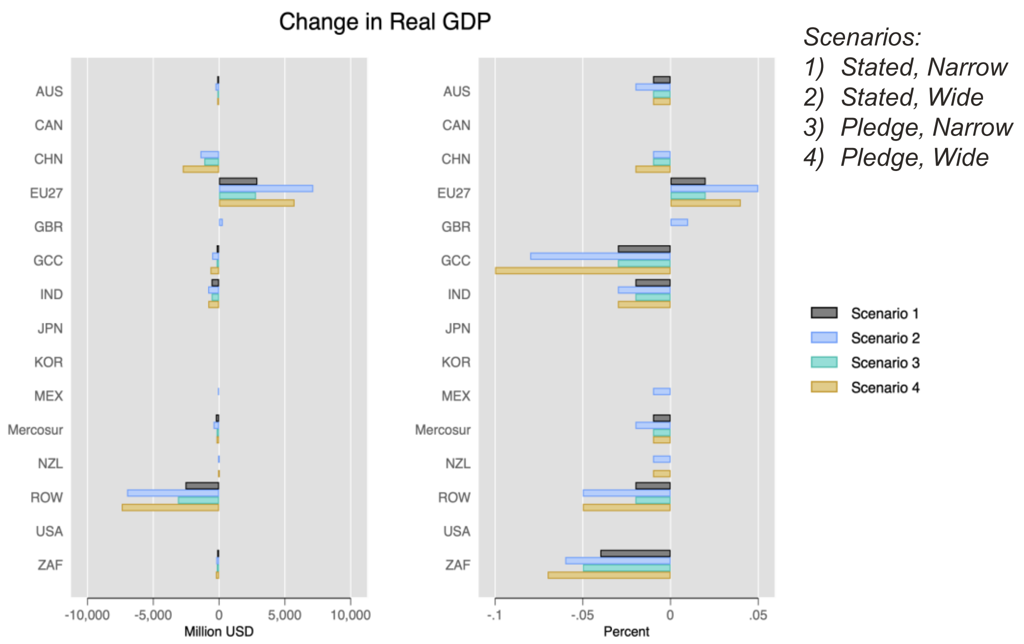
The results are what we would expect to see from an intervention that changes relative prices in favour of certain sectors, which is the case with the CBAM. The *ad valorem* duties encourage a reallocation of resources to domestic and EU sources of production for CBAM sectors, which are the ones favoured by the duties. By contrast, they increase import competition from non-CBAM sectors, specifically those outside the EU. The CBAM preserves the competitiveness (in terms of exposure to imports) of covered sectors, but for the same reason increases the exposure of non-covered sectors, and also reduces UK trade (imports and exports) in aggregate.

GDP effects

Figure 10 reports GDP effects for the UK, the EU and a selection of their major trading partners. The main transmission mechanism between the CBAM and GDP is via the terms of trade – the price of its exports in terms of its imports. The EU experiences a significant terms of trade gain that produces an increase in real GDP. For the UK, effects on real GDP are zero, or, in one case, positive but exceedingly small. The differences between the UK and the EU reflects the differences in their size. The larger size of the EU means changes in demand induced by CBAM have an effect on its import prices, whereas this effect is more limited for the UK.

Economic exposure in partners to the CBAM is driven by magnitude of *ad valorem* duties (which reflect the gap between their emissions prices and UK and EU ones), and the importance of CBAM products to these economies. The biggest exposure lies in Sub-Sharan Africa and the Gulf states.

Figure 10 Impact of CBAM on GDP by country group under the four main scenarios



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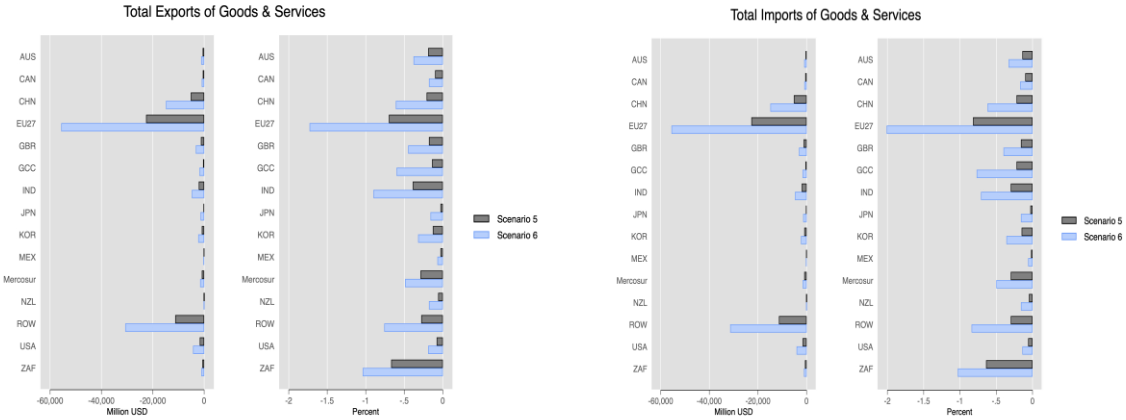
Trade impacts – maximal scenarios

Aggregate effects

Figure 11 reports the aggregate trade and export effects for scenarios 5 and 6. They are similar to scenarios 3 and 4, though more pronounced because of the higher rates of *ad valorem* duties that are associated with scenarios 5 and 6.

Figure 11 Impact of CBAM on trade flows by country group under the maximal scenarios



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Sectoral trade effects

Figure 12 reports changes to UK imports by sector, and Figure 13 does the same for exports. The pattern of results is the same as with the core scenarios. The magnitudes are larger because of the higher duties involved.

Figure 12 Impact of CBAM on UK imports by sector under the maximal scenarios

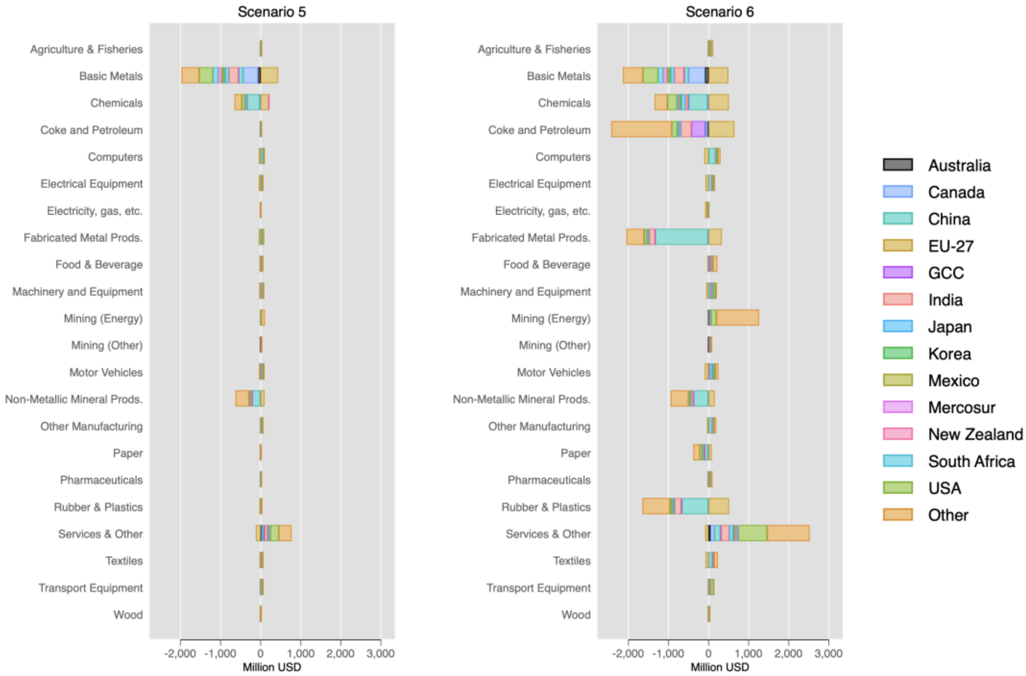
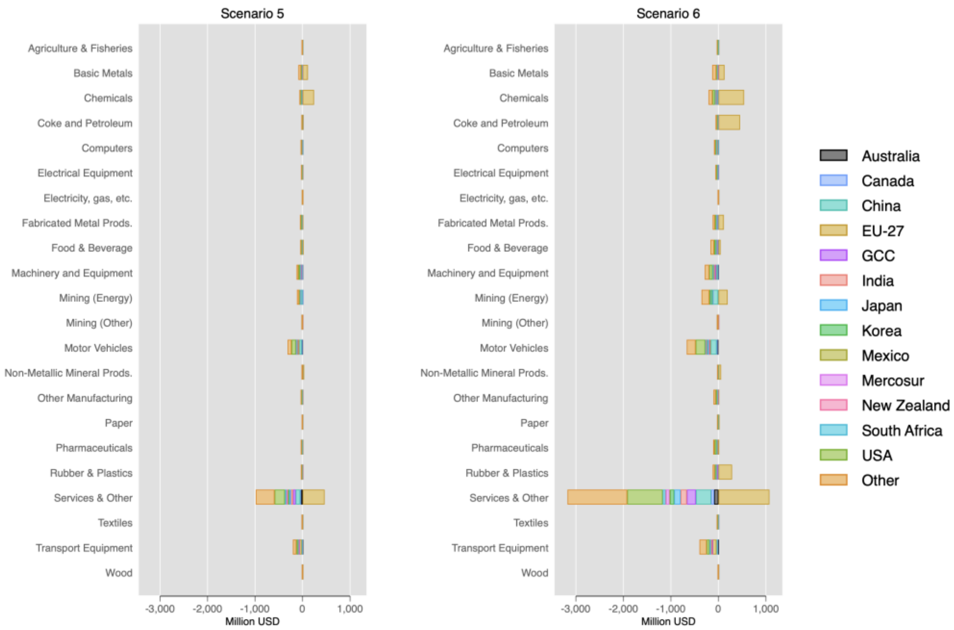


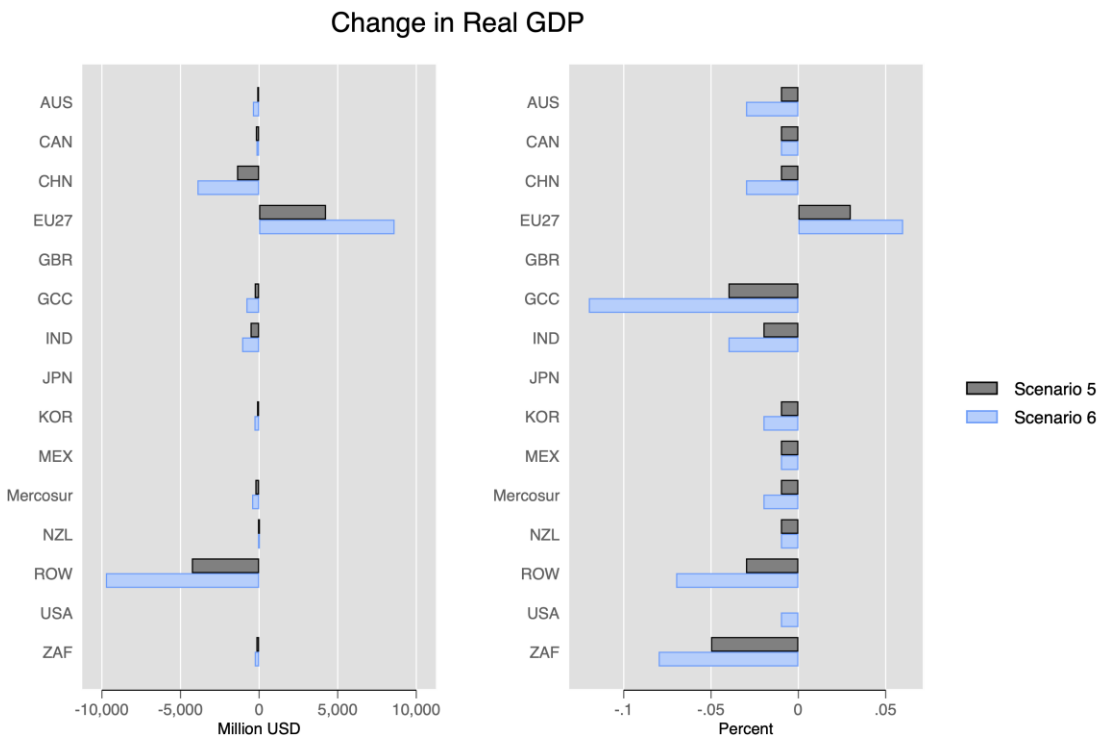
Figure 13 Impact of CBAM on UK exports by sector and destination under the maximal scenarios



GDP effects

The transmission from the CBAM to GDP effects follows the terms of trade effect described in preceding sections. For these scenarios, effects on UK GDP are nil, slightly positive for the EU, and negative for other regions in proportion to their CBAM exposure.

Figure 14 Impact of CBAM on GDP by country group under the maximal scenarios



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Conclusion and further steps

The effects of the CBAM

The modelled effects of the CBAM correspond to what we would expect from the imposition of an *ad valorem* duty on a specific class of imported products. The CBAM generates revenue, and also leads to substitution away from trade to domestic production, and also from high emissions to low emissions import sources. The effects are analogous to a traditional trade tariff, with preferential access granted to a subset of importers (in this case, partners with low emissions and emissions pricing schemes). Tariff revenues increase to the extent that substitution effects are more limited, though that would also mean that the CBAM is not meeting its primary role which is to correct for the risk of carbon leakage.

The substitution effects alluded to above are ones we would expect from any change in relative prices brought about by the imposition of *ad valorem* duties on selected traded goods. They reduce the exposure to import competition of CBAM sectors, and also favour trade in these products between the UK and the EU, who jointly constitute a CBAM-free zone. The same relative price effect also increases the exposure of non-CBAM sectors, particularly services sectors, to imports, and reduces exports. In aggregate, UK imports and exports fall. The effects are consistent with the idea that, in trade terms, “competitiveness” is a notion that is applicable to specific sectors but is not one that is relevant to economies as a whole. A decision to support certain industries by influencing relative prices is necessarily a decision to reallocate resources away from others. The reported GDP effects suggest that, in comparative static terms (i.e. comparing the state of the world with a CBAM versus that without a CBAM), the decision does not leave the UK as a whole worse off.

Further steps

As already observed, the CBAM is intended to have two “legs”: an import leg which imposes emissions prices on imports, and an export leg that exempts exports from domestic emissions prices, so that they are not placed at a disadvantage on global markets. CBAM proposals, and this modelling, focuses only on the import leg.

Discussion on solutions to the export leg have so far been inconclusive, notably in the EU which has already begun the implementation of the import leg. This is largely due to uncertainties about the appropriate administrative design, in particular whether this should take the form of free permit allocations tied to exporting or outright exemptions from ETS obligations.

The free permit route and the exemption route are analytically similar in economic terms. Assuming that a particular UK industry is a price-taker on global markets, the effect of an emission price would be to raise the costs of supplying an extra unit of production on the word market, and this leads to a fall in UK sales on global markets and a corresponding increase in sales from other sources. An export solution would negate this effect. Unlike the CBAM's import "leg", the export solution does not need to be calibrated to the emissions price in the export market. This is because, in the case of the export solution, the intention is not to compensate for the differential between UK and partner emissions prices, but purely to offset the effects of the UK's emissions price.

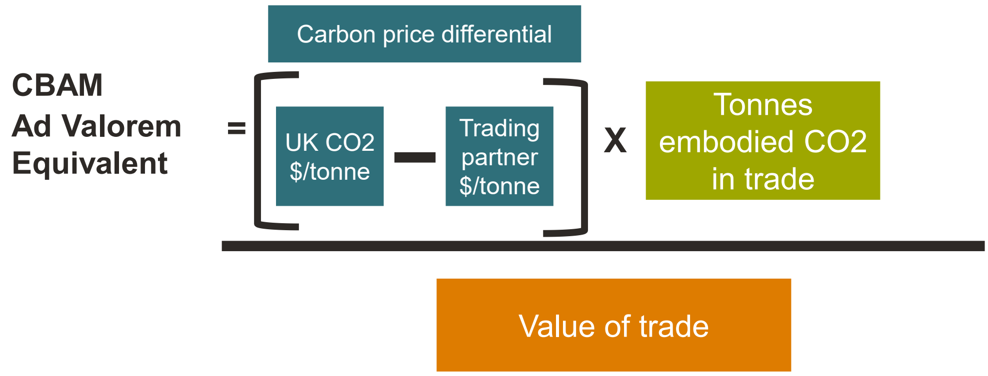
In terms of modelling, one option would be to estimate the effects of an emissions price as a specific *ad valorem* export charge on UK exports in line with emissions intensity. The export solution would simply negate the effects of this export charge. The modelling results presented in this report on trade effects provide some qualitative guidance as to how these effects may play out. The emissions price would reduce exports of emissions intensive goods, but by the same token they would also increase the exports of non-emissions intensive sectors (such as services) by shifting relative prices in favour of these sectors and favouring resource reallocation towards them. The export solution would reverse these effects.

The main issues turn around the responses of trade partners. Parties may impose countervailing duties – as the United States has on free ETS permit allocations for certain steel products. Or it may be that some partners also gravitate towards the use of a CBAM type arrangement, and impose CBAM duties.

Annex A – methodology for calculating CBAM rates

This Annex describes the various steps used to calculate CBAM rates, which are the *ad valorem* rates that would be applicable to a particular import, from a particular country of origin, based on differentials in emissions prices and on the embodied emissions intensity of the imports. This is captured in the schematic below:

Figure 15 Overview of approach to calculating CBAM *Ad Valorem* rates



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Calculation of embodied CO_2

The first step is to calculate how much carbon is embodied in each $ of trade. The concept of 'embodied emission' means the emissions emitted at various stages of the supply chain that go in to making the final product, including both direct emissions and indirect emissions. We need to use a source for this that: (i) offers standardised methodology across countries of interest, and (ii) maps on to trade data, since the CBAM applies to traded goods and the emissions embodied in them.

Some estimates of CO_2 emissions by sector are possible from drawing on industry data on resource use, or physical/engineering modelling of certain productive processes. However, these sources will be incomplete, are likely to lack any systematic depth to understand upstream uses of carbon or indirect emissions, and do not meet conditions (i) and (ii) set out above.

We therefore use the OECD Trade in Embodied CO_2 ($TECO_2$) dataset. This is based on internationally interlinked input-output tables. It enables a complete understanding of inputs of inputs up to an infinite order, fully capturing indirect uses.[4] The $TECO_2$ data complete and authoritative, and runs up to 2018.

One of the advantages is that it has the same structure as the OECD Trade In Value Added (TiVA) dataset: this reports trade flows between countries, which is used as the denominator in the CBAM calculation. The TiVA data base is also required for trade modelling since it accounts for intra-country trade, as well as trade between countries.[5] Taking into account intra-country trade is necessary to avoid biases in the estimates of policy impacts on trade flows between countries. The joint use of $TECO_2$ and TiVA databases allows the CBAM ratios to be applied seamlessly.

TiVA and $TECO_2$ cover 45 sectors and 65 countries. One of the challenges in using these sources is that the level of aggregation does not correspond perfectly with all the product categories identified as coming (or potentially coming) under the scope of the CBAM. This is the case for: iron and steel + aluminium vs. 'non-core' metals, fertiliser vs. other chemicals, and cement vs. other non-metallic mineral products.

The datasets used are Trade in Value Added (TiVA),[6] which measures the value of trade and Trade in Embodied CO_2 ($TECO_2$),[7] which gives the corresponding quantity of embodied emissions. Together the datasets give a complete and exhaustive attribution of trade and CO_2. CBAM rates can then be inputted into the equilibrium model to estimate how trade flows change in response to the CBAM. Note, however, that the OECD datasets are at a more aggregate level than some of the covered products, and where appropriate we use additional data sources to focus only on the covered products.

The schematic captures how the emissions price differential is applied to tonnes of embodied emissions, measured in CO_2 equivalents. That figure is divided by the value of bilateral trade between the UK and the partner to give the *ad valorem* rate. Note that for some products that come within the scope of the CBAM, both trade and embodied emissions data are available at the level of that product. In other cases, the data are available but only at a higher degree of aggregation. In such cases, it is necessary to derive shares of the both trade and emissions from these aggregated that apply to the product that is specifically covered by the CBAM.

We draw on additional datasets ITPD-E and BIMITS, which reports trade volumes at a more disaggregated level than in TiVA/$TECO^2$. This gives shares of trade value covered by CBAM. Trade value shares are converted to CO^2 volume shares using assumed loadings, i.e. how much more CO_2 the CBAM sector emits than adjacent non-CBAM sectors. CO_2 loadings are calculated using overall shares of trade value from the data and comparing with estimates of CO_2 shares from the International Energy Agency. For example, iron and steel accounts for

[4] Yamano, N. and J. Guilhoto (2020), "CO_2 emissions embodied in international trade and domestic final demand: Methodology and results using the OECD Inter-Country Input-Output Database", OECD Science, Technology and Industry Working Papers, No. 2020/11, OECD Publishing, Paris, https://doi.org/10.1787/8f2963b8-en. The data can be downloaded from https://www.oecd.org/sti/ind/carbondioxideemissionsembodiedininternationaltrade.htm

[5] See https://www.oecd.org/sti/ind/measuring-trade-in-value-added.htm

[6] https://www.oecd.org/sti/ind/measuring-trade-in-value-added.htm

[7] https://www.oecd.org/industry/ind/carbondioxideemissionsembodiedininternationaltrade.htm

52% of metal production value but 76% of CO_2 emissions, so has an emissions intensity 143% of the metals sector average.

An additional step in calculating embodied carbon is the concept of Scope 1, 2 and 3 emissions. These are discussed in the UK decarbonisation leakage consultation document.[8] Essentially, Scope 1 emissions are those directly emitted by the production sector (e.g. fuel combusted during iron smelting), Scope 2 emissions relate to energy consumption and Scope 3 to intermediate inputs. Scope 3 emissions do not fall within the UK CBAM proposals. To capture this, we are able to use input-output table analysis to attribute the emissions of an exporting sector to the respective sector inputs it uses. This lets is strip out the Scope 3 emissions, and include only Scope 1 and Scope 2 in the CBAM calculations. Scope 3 accounts for typically 15% of emissions in the context of the sectors analysed.

Country carbon pricing assumptions

The carbon pricing assumptions are based on a 'stated' scenario of $90/tonne and a 'pledge' scenario of $135/tonne. However, the CBAM does not necessarily seek to recover the full amount of the carbon price, only the differential between the UK carbon price and the price deemed to be in operation in the partner country.

In "stated", we assume that only countries with an emissions price covering their entire territory have an emissions price. These are the UK, EU, Canada, China, Japan, New Zealand, South Korea and Switzerland. The UK and EU are assumed to have the same carbon price, so therefore do not apply CBAM rates to each other.

In the "pledge" scenario, we assume emissions prices in line with their pledged greenhouse gas reduction targets. Many countries will now have a positive carbon price, and hence reduction in CBAM. The following carbon price assumptions are used:

- 100% - UK, EU, EFTA, Singapore;
- 75% - OECD;
- 50% - China, Argentina, Brazil;
- 25% - Russia and Kazakhstan;
- 10% Rest of World.

In the maximal scenarios, it is assumed that no origin credit is applied and that it is as if the trading partner had a zero carbon price and therefore the full CBAM rate would be applied.

8 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1149568/UPDATED_FINAL_CONDOC_-_HMG_TEMPLATE_-_ADDRESSING_CARBON_LEAKAGE_RISK_TO_SUPPORT_DECARBONISATION.pdf

Product coverage

Table 1 sets out the products covered in the core scenario. The first column shows the relevant OECD sectors, with the second and third columns specifying which products within it are covered or not covered.

Table 1 Product coverage – core scenario

Sector	Covered	Not covered
Chemicals	Fertiliser	Other chemicals
Other non-metallic minerals	Cement	Glass, ceramics, plaster, lime
Basic metals	Iron and steel, aluminium	Other non-ferrous basic metals

Similar assumptions are shown for the wide scenario in Table 2 below. With the exception of non-metallic minerals, in the wide scenario the OECD sectors that fall within scope are covered in their entirety.

Table 2 Product coverage – wide scenario

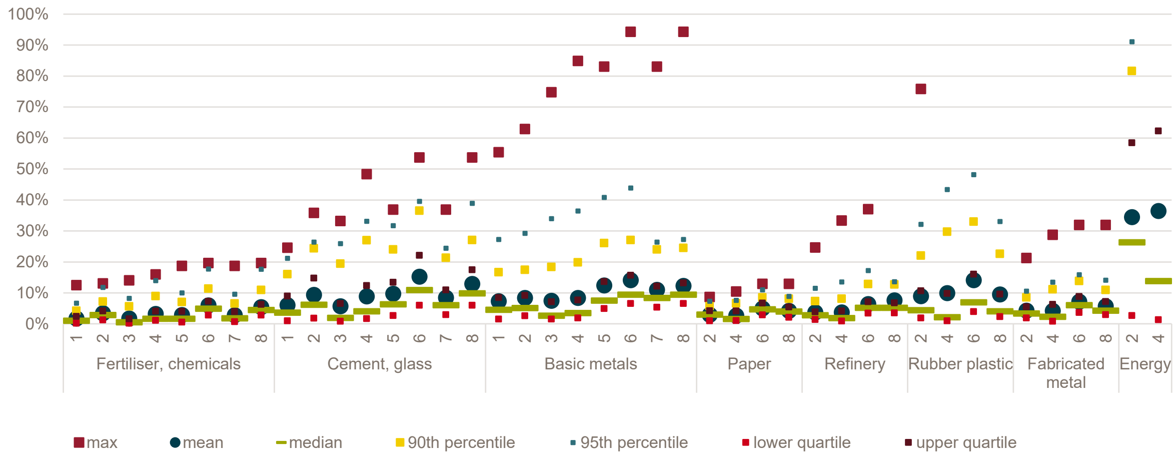
Sector	Covered	Not covered
Paper products and printing	All	
Chemicals and non-metallic mineral products	All	
Coke and refined petroleum products	All	
Chemical and chemical products	All	
Rubber and plastics products	All	
Other non-metallic mineral products[9]	All	
Basic metals	All	
Energy	All	

[9] The 'other non-metallic mineral products' category includes products such as cement, glass, mortar, lime, ceramics and porcelain. The UK consultation document at times refers specifically to cement and glass, and at other points to non-metallic minerals more generally. Cement is widely cited as a significant source of carbon emissions, so we propose to include only cement within that product group for the 'core' scenario, and the full product group in the 'wide' scenario.

Summary of CBAM rates

The distribution of CBAM rates across trading partners is shown in the chart below. Sectors are listed horizontally, with the scenarios numbered in sequence. The data points represent different summary statistics of the distribution, namely the max, mean, median, upper percentiles and quartiles. As can be seen some very high rates are observed, particularly for basic metals. In such cases, we would see these trade flows heavily affected, which would induce substitution away from that exporter and erosion of the tax base.

Figure 16 Distribution of CBAM rates by sector and scenario



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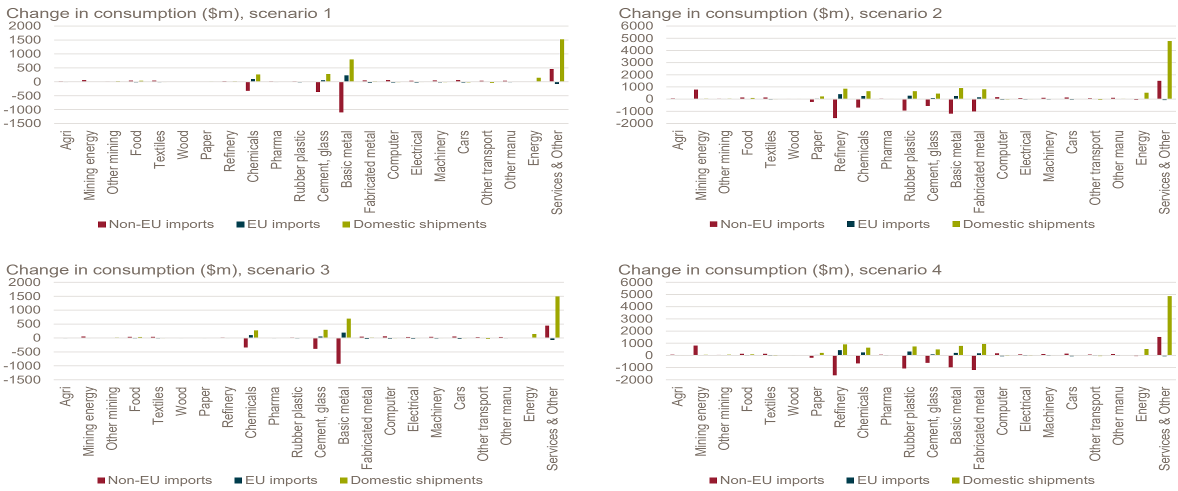
Annex B – Detailed modelling results

Effects on domestic production

The reduction in imports from non-EU countries is partially offset by imports from the EU, as well as increased consumption of domestic production. While the increase in 'domestic shipments' is large in absolute terms and meets most of the shortfall, in relative terms the increase is fairly small, in the region of 2-5% for the affected sectors.

Figure 17 Changes in UK consumptrion by sector and source under four main scenarios



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Note: *[Insert Notes]*

EU-only baseline

Figure 18 Effect of an EU-only CBAM on countries' trade

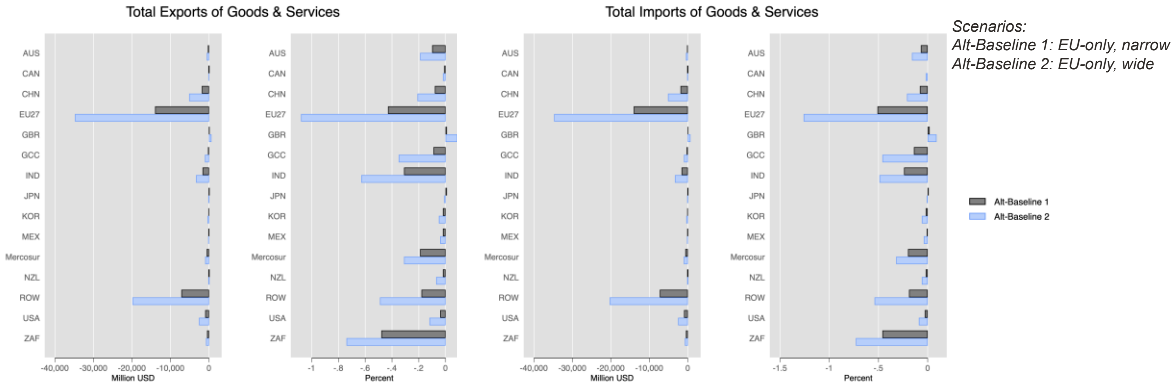

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Figure 19 Effect of an EU-only CBAM on UK imports by sector

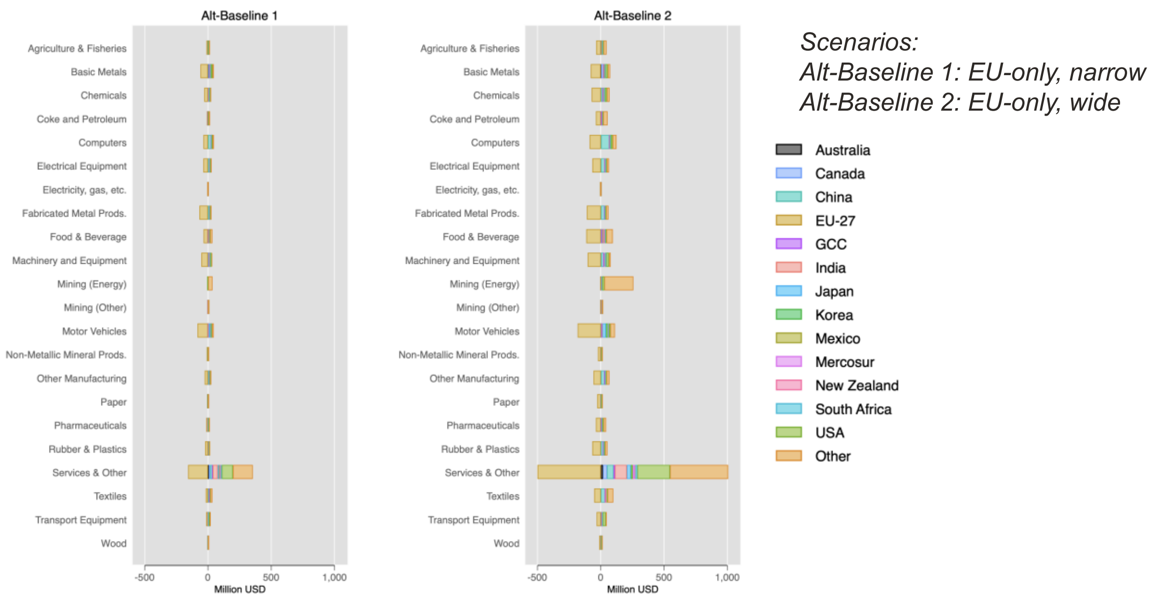

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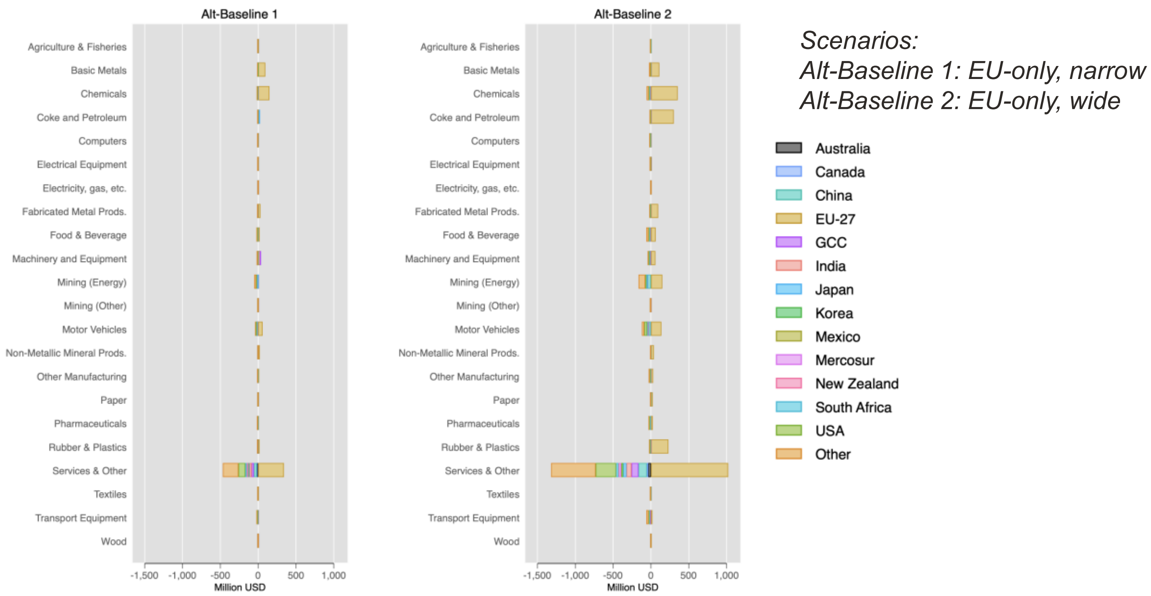
Figure 20 Effect of an EU-only CBAM on UK exports by sector



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Annex C – technical description of the model

We model the economic impacts of measures enacted under the scenarios described in the main by using a model from the class of general equilibrium models known as New Quantitative Trade Models (NQTMs). Academic economists now typically use NQTMs for the analysis of trade policy changes, ranging from entry into a trade agreement,[10] to joining the WTO.[11] The model used here is based on articles published in leading academic journals, and has previously been applied in peer-reviewed research to, for instance, analyse the economic impacts of improvements in trade facilitation.[12]

NQTMs, like all economic models, have a complex structure embodied in a large set of equations linked to a dataset. However, the basic logic is straightforward, and is based on a widely shared understanding of how policy changes affect trade flows and prices, and how they in turn affect economic welfare. Figure 1 summarizes the NQTM's approach to turning inputs (changes in policies, expressed as *ad valorem* equivalent trade costs; see main text for details of calculations) into outputs (changes in real Gross National Income, GNI, as a measure of economic welfare, as well as intermediate variables like prices and trade values).

In essence, the policy change leads to a change in relative prices, which feeds directly through to consumer prices, and also indirectly through its effect on production costs. These price changes then influence each country's terms of trade — the price of its exports in terms of its imports—and the composition of its trade, meaning exports and imports in particular sectors and with individual country partners. The net outcome of these different effects, which are complex at a micro-level, is measured by changes in real GNI. A key feature of all general equilibrium trade models, including this one, is that expansions in import competing sectors due to an increase in their relative price must necessarily draw resources from exporting sectors; trade economists therefore universally acknowledge that "a tax on imports is a tax on exports".

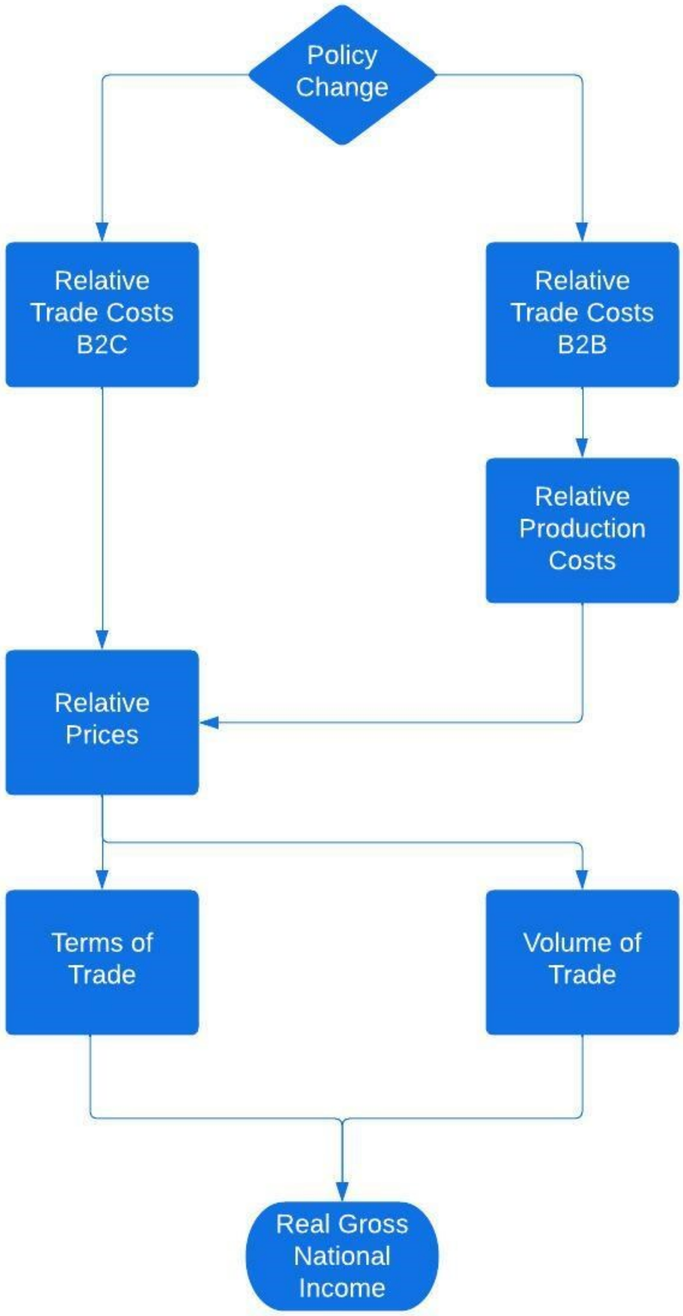
The net outcome of any policy change fed into the model is ambiguous due to the large number of effects at play. In particular, terms of trade effects and volume of trade effects can act in opposite directions, or they can act in different ways for different countries. So, the model solves for an equilibrium of the world economy in which a set of macroeconomic constraints hold, and reported results are based on this equilibrium.

[10] Caliendo, L., and F. Parro. 2015. "Estimates of the Trade and Welfare Effects of NAFTA." Review of Economic Studies, 82(1): 144.

[11] Aichele, R., and I. Heiland. 2018. "Where is the Value Added? Trade Liberalization and Production Networks." Journal of International Economics, 115(C): 130-144.

[12] Shepherd, B. 2022. "Modelling global value chains: From trade costs to policy impacts", World Economy, 45(8): 2478-2509.

Figure 21 Simplified flowchart of the NQTM



In the version of the model used here, there are 21 sectors and nine countries. This arrangement is based on an aggregation of the OECD-WTO Trade in Value Added Database (TiVA), which is based on a global input-output table of the type needed by the NQTM. Country coverage is based on identification of major global traders including the EU and its main partners, with other countries summed into an aggregate "rest of the world" (ROW) region.[13] Sectoral coverage is based on individual treatment of sectors that are subject to policy changes under the scenarios discussed above; remaining sectors are summed into aggregates. The model therefore works with a large database, and produces both macro-level results such as changes in real Gross National Income (GNI), as well as micro-level findings such as changes in exports of a particular sector between two countries.

Like any economic model, however, the NQTM used here has important limitations. Its most appropriate use comes from comparing scenario outcomes in relative terms: they summarise the relative extent of changes in economic variables for a constant model structure, and therefore give a useful indication of the relative magnitudes of changes. Interpretation in absolute terms is less helpful, as model structure clearly plays a role in determining results.

The general flow of the NQTM was described above. Mathematical details are below. From a conceptual perspective, key limitations of the model, which are common to many standard trade modelling frameworks, are:

- **Comparative static, all else constant**: The model compares equilibria under the baseline (observed) state of the world economy (2018 in this case), and a counterfactual economy in which trade costs change due to a set of policy changes, but all other factors remain constant. As such, there is no time dimension to the model, and it does not describe the dynamic path by which an economy moves from one equilibrium state to another. Results can therefore be interpreted as answering the question "how different would the 2018 world economy look if policies changed in a defined way, but everything else stayed the same?". Results are an annual change in variables concerned, but they should not be likened to predictions, projections, or forecasts.

- **No savings or investment**: Linked to the comparative static structure of the model is the fact that there is no modelling of savings and investment decisions. As such, each country's aggregate trade balance is identical in the baseline and counterfactual equilibria. The absence of savings and investment decisions means that there is no accumulation effect over time, as changes in trade costs affect the decision whether to consume or save/invest.

- **Single factor of production, full employment**: The NQTM has labour as the only factor of production, and assumes full employment. As such, it cannot produce results on sectoral or aggregate changes in employment.

- **Variable cost changes only**: Both the procedure adopted above for translating policy changes into cost impacts and the NQTM itself assume that policy changes only affect variable (*ad valorem*) trade costs. The model does not consider economic effects that the policies could have over and above this. In particular, it does not analyse changes

[13] For technical reasons, very small economies are also aggregated. The model therefore uses "BLX" to indicate an aggregate of Belgium, the Netherlands, and Luxembourg, and "OEU" to indicate Malta and Cyprus.

in marketplace competition that could be associated with a broader range of policy effects, such as changes to entry conditions.

Consumption Side

The consumption side of the model comes from Caliendo and Parro (2015). A measure Ln of representative households in N countries (subscript) maximize Cobb Douglas utility by consuming final goods in J sectors (superscript), with consumption shares α_n^j summing to unity.

$$(1)\ u(C_n) = \prod_{j=1}^{J} \left(C_n^j\right)^{\alpha_n^j}$$

Production Side

The production side of the model also comes from Caliendo and Parro (2015) via Aichele and Heiland (2018), which can be seen as a multi-sector generalization of Eaton and Kortum (2002). As in Aichele and Heiland (2018), there is provision for different shares in intermediate and final consumption

Each sector produces a continuum of intermediate goods $\omega^j \in [0,1]$. Each intermediate good uses labor and composite intermediate goods from all sectors. Intermediate goods producers have production technology as follows:

$$(2)\ q_n^j(\omega^j) = z_n^j(\omega^j)\left[l_n(\omega^j)\right]^{\beta_n^j} \prod_{k=1}^{J} \left[m_n^{k,j}(\omega^j)\right]^{\gamma_n^{k,j}}$$

Where: $z_n^j(\omega^j)$ is the efficiency of producing intermediate good ω^j in country n; $l_n(\omega^j)$ is labour; $m_n^{k,j}(\omega^j)$ are the composite intermediate goods from sector k used for the production of intermediate good ω^j; and β_n^j is the cost share of labour and $(1-\beta_n^j)\gamma_n^{k,j}$ is the cost share of intermediates from sector k used in the production of intermediate good ω^j, with $\sum_{k=1}^{J} \gamma_n^{k,j} = 1$.

Production of intermediate goods exhibits constant returns to scale with perfect competition, so firms price at marginal cost. The cost of an input bundle can therefore be written as follows:

$$(3)\ c_n^j = \Upsilon_n^j w_n^{\beta_n^j} \left(\prod_{k=1}^{J} \left(P_n^{km}\right)^{\gamma_n^{k,j}} \right)^{1-\beta_n^j}$$

Where: P_n^{km} is the price of a composite intermediate good from sector k; w is the wage; and Υ_n^j is a constant.

Producers of composite intermediate goods in country n and sector j supply their output at minimum cost by purchasing intermediates from the lowest cost suppliers across countries, similar to the mechanism in the single sector model of Eaton and Kortum (2002).

Composite intermediate goods from sector j are used in the production of intermediate good ω^k in amount $m_n^{j,k}(\omega^k)$ in all sectors k, as well as final goods in consumption C_n^j. The composite intermediate is produced using CES technology:

$$(4)\ Q_n^j = \left[\int r_n^j(\omega^j)^{1-\frac{1}{\sigma^j}} d\omega^j\right]^{\frac{\sigma^j}{\sigma^j-1}}$$

Where: r is demand from the lowest cost supplier, and σ is the elasticity of substitution across intermediate goods within a sector.

Solving the producer's problem gives an expression for demand:

$$(5)\ r_n^j(\omega^j) = \left(\frac{p_n(\omega^j)}{P_n^j}\right)^{-\sigma^j} Q_n^j$$

Where: $p_n(\omega^j)$ is the lowest price of a given intermediate good across countries; and $P_n^j = \left[\int p_n(\omega^j)^{1-\sigma^j} d\omega^j\right]^{\frac{1}{1-\sigma^j}}$ is the CES price index.

Trade Costs and Equilibrium

Trade costs consist of tariff and NTM components as in Aichele and Heiland (2018), in the standard iceberg formulation for imports by country n from country i, with trade costs potentially differing by end use (intermediate, m, or final, f):

$$(6)\ \kappa_{ni}^{jv} = \left(1 + t_{ni}^{jv}\right) * \tilde{t}_{ni}^{jv}, v \ni (m, f)$$

Where t is the *ad valorem* tariff, and $\tilde{t}$ is NTM-related trade costs, including potentially policy measures but also geographical and historical factors that drive a wedge between producer prices in the exporting country and consumer prices in the importing country (Anderson and Van Wincoop, 2004). Unlike in Caliendo and Parro (2015), we assume that all sectors are tradable; this assumption accords with the reality in our data, where sectors are sufficiently aggregate that trade always takes place, at least to some degree.

With this definition of trade costs, the price of a given intermediate good in country n is:

$$(7)\ p_n^j(\omega^j) = \min_{\mathrm{i}} \frac{c_i^j \kappa_{ni}^{jm}}{z_i^j(\omega^j)}$$

As in Eaton and Kortum (2002), the efficiency of producing ω^j in country n is the realization of a Fréchet distribution with location parameter $\lambda_n^j \geq 0$ and shape parameter $\theta^j > \sigma^j - 1$. The intermediate price index can therefore be rewritten as:

$$(8)\ P_n^{jm} = A^j \left[\sum_{i=1}^{N} \lambda_i^j \left(c_i^j \kappa_{ni}^{jm} \right)^{-\theta^j} \right]^{-\frac{1}{\theta^j}}$$

Where A^j is a constant.

Then from the utility function, prices are:

$$(9)\ P_n^f = \prod_{j=1}^{N} \left(\frac{P_n^{jf}}{\alpha_n^j} \right)^{\alpha_n^j}$$

Bringing together these ingredients gives a relationship for bilateral trade at the sector level that follows the general form of structural gravity, but developed in an explicitly multi-sectoral framework and with different relations for intermediate and final consumption:

$$(10)\ \pi_{ni}^{jv} = \frac{X_{ni}^{jv}}{X_n^{jv}} = \frac{\lambda_i^j \left[c_i^j \kappa_{ni}^{jv} \right]^{-\theta^j}}{\sum_{h=1}^{N} \lambda_h^j \left[c_h^j \kappa_{nh}^{jv} \right]^{-\theta^j}}$$

For analytical purposes, a key feature of the gravity model in equation 10 is that the unit costs term depends through equation 3 on trade costs in all sectors and countries. This result is an extension of the multilateral resistance reasoning in Anderson and Van Wincoop (2003) to the case of cross-sectoral linkages.

Goods market equilibrium is defined as follows, where Y is the gross value of production:

$$(11)\ Y_n^j = \sum_{i=1}^{N} \frac{\pi_{in}^{jm}}{1 + t_{in}^{jm}} X_i^{jm} + \sum_{i=1}^{N} \frac{\pi_{in}^{jf}}{1 + t_{in}^{jf}} X_i^{jf}$$

With:

$$(11)\ X_n^{jm} = \sum_{k=1}^{J} \frac{\pi_{in}^{jm}}{1 + t_{in}^{jm}} \gamma_h^{j,k} \left(1 - \beta_h^k \right) Y_h^k$$

$$(12)\ X_n^{jf} = \alpha_n^j I_n$$

National income is the sum of labour income, tariff rebates, and the exogenous trade deficit:

$$(12)\ I_n = w_n L_n + R_n + D_n$$

The model is then closed by setting income equal to expenditure:

$$(13)\ \sum_{j=1}^{J} X_n^{jm} \sum_{i=1}^{N} \frac{\pi_{ni}^{jm}}{1+t_{ni}^{jm}} + \sum_{j=1}^{J} X_n^{jf} \sum_{i=1}^{N} \frac{\pi_{ni}^{jf}}{1+t_{ni}^{jf}} - D_n = \sum_{j=1}^{J} Y_n^j$$

Where: I represents final absorption as the sum of labour income, tariff revenue, and the trade deficit; R is tariff revenue, and trade deficits sum to zero globally and to an exogenous constant nationally. So aggregate trade deficits are exogenous, but sectoral deficits are endogenous.

Caliendo and Parro (2015) show that the system defined by equations 3, 8, 10, 11, and 13 can be solved for equilibrium wages and prices, given tariffs and structural parameters.

Counterfactual Simulation

Using exact hat algebra (Dekle et al., 2007), it is simpler to solve the model in relative changes than in levels. This process is equivalent to performing a counterfactual simulation in which a baseline variable v is shocked to a counterfactual value v', and the relative change is defined as $\hat{v} = \frac{v'}{v}$. Aichele and Heiland (2018) show that counterfactual changes in input costs are given by:

$$(14)\ \hat{c}_n^j = \widehat{w}_n^{\beta_n^j} \left(\prod_{k=1}^{J} \hat{P}_n^{k_m \gamma_n^{k,j}} \right)^{1-\beta_n^j}$$

The change in the price index is:

$$(15)\ \hat{P}_n^{jv} = \left[\prod_{i=1}^{N} \pi_{ni}^{jv} \left[\hat{\kappa}_{ni}^{jv} \hat{c}_i^j \right]^{-\theta^j} \right]^{-\frac{1}{\theta^j}}$$

The change in the bilateral trade share is:

$$(16)\ \hat{\pi}_{ni}^{jv} = \left[\frac{\hat{\kappa}_{ni}^{jv} \hat{c}_i^j}{\hat{P}_n^{jv}} \right]^{-\theta^j}$$

Counterfactual intermediate goods and final goods expenditure are given by:

$$(17)\ X_n^{jm'} = \sum_{k=1}^{N} \gamma_n^{j,k} \left(1-\beta_n^k\right) \left(\sum_{i=1}^{N} X_i^{km'} \frac{\pi_{in}^{km'}}{1+t_{in}^{km'}} + X_i^{kf'} \frac{\pi_{in}^{kf'}}{1+t_{in}^{kf'}} \right)$$

With:

$$(18)\ X_n^{jf'} = \alpha_n^j I_n'$$

$$(19)\ I_n' = \widehat{w}_n w_n L_n + \sum_{j=1}^{J} X_n^{jm'}\left(1 - F_n^{jm'}\right) + \sum_{j=1}^{J} X_n^{jf'}\left(1 - F_n^{jf'}\right) + D_n$$

The trade deficit condition requires:

$$(20)\ \sum_{j=1}^{J} F_n^{jm'} X_n^{jm'} + \sum_{j=1}^{J} F_n^{jf'} X_n^{jf'} - D_n = \sum_{j=1}^{J}\sum_{i=1}^{N} X_i^{jm'} \frac{\pi_{in}^{jm'}}{1 + t_{in}^{jm'}} + \sum_{j=1}^{J}\sum_{i=1}^{N} X_i^{jf'} \frac{\pi_{in}^{jf'}}{1 + t_{in}^{jf'}}$$

The change in welfare is given by the change in real income:

$$\widehat{W}_n = \frac{\widehat{I_n}}{\prod_{j=1}^{J}\left(\hat{p}_n^{jf}\right)^{\alpha_n^j}}$$

The relative change in trade costs is given by the definition of the counterfactual simulation, and in our specification can cover NTMs as well as tariffs. Solving the model using exact hat algebra makes it possible to conduct the counterfactual experiment without data on productivity, and importantly, without trade costs data other than those that are being simulated; due to the multiplicative form of iceberg trade costs, solution in relative changes means that trade cost components, such as geographical and historical factors, which are constant in the baseline and counterfactual simply cancel out. The parameters β_n^j (cost share of labour), $(1 - \beta_n^j)\gamma_n^{k,j}$ (cost share of intermediates), and α_n^j (share of each sector in final demand) can be calibrated directly from the baseline data, as can value added ($w_n L_n$). Egger et al. (2018) provide updated estimates of the trade elasticity θ^j at the same level of disaggregation used in our data.

Caliendo and Parro (2015) develop an iterative procedure for solving the model, which we follow here in the modified version developed by Aichele and Heiland (2018).