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Front-Loading at the Carbon Border: Early Evidence on EU Imports under the Carbon Border Adjustment Mechanism

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Abstract

The European Union's Carbon Border Adjustment Mechanism (CBAM) is the first broad border carbon adjustment, yet evidence on its trade effects comes almost entirely from simulations. We provide early ex post evidence using monthly Eurostat data on EU imports of 593 products from 200 non-EU exporters, January 2019 to June 2026. Exploiting CBAM's staged introduction, we compare covered iron and steel, aluminium, fertiliser and cement imports with non-covered products from the same exporters in a Poisson pseudo-maximum-likelihood difference-in-differences design. Covered imports did not fall when CBAM was proposed, adopted or entered its emissions-reporting phase. The clearest response is anticipatory: relative to comparable non-covered products, covered imports rose by about 22 per cent in the final quarter before carbon costs applied in January 2026 and fell by about 7 per cent in the first half of 2026. Effects in the definitive period range from zero to a decline of about 23 per cent, depending on how pre-existing trends are treated, and covered exports from lower-income countries fell by about 25 per cent relative to those from higher-income countries. Early adjustment has worked through the timing of shipments rather than market exit, so evaluations that ignore front-loading will overstate CBAM's effect.

JEL classification: F13; F14; F18; Q56; Q58

1. Introduction

For a long time, border carbon adjustments were studied mainly in theoretical and simulation models. The European Union has now put one into practice. Under Regulation (EU) 2023/956, importers of iron and steel, aluminium, fertilisers, cement, hydrogen and electricity into the European Union must report the greenhouse gases embedded in those goods and, from 2026, pay for them at a price linked to the EU Emissions Trading System. The policy aims to prevent carbon leakage, meaning the relocation of emission-intensive production to countries with weaker climate policy, and to encourage trading partners to price carbon themselves. Its critics, many of them in developing countries, argue that it is a trade barrier dressed as climate policy that will cut their exports to Europe.

Most of what is known about CBAM's trade effects comes from simulations. Computable general equilibrium and structural gravity models predict reductions in the EU's imports of covered goods, with larger losses for carbon-intensive exporters (Böhringer et al., 2012; Larch and Wanner, 2017; Zhong and Pei, 2022). These predictions depend on assumptions about elasticities, carbon prices and the scope of the measure that cannot be checked before the policy is in force. Now that CBAM has passed through its reporting phase and into its definitive period, observed trade data can begin to answer the question directly.

This paper provides early empirical evidence on how EU imports responded to each stage of CBAM. The staged introduction is useful for identification and for understanding mechanisms. The proposal (July 2021) and adoption (May 2023) created expectations without any obligation. The reporting phase (October 2023 to December 2025) imposed compliance costs but no carbon price. Importers had to

obtain installation-level emissions data from foreign producers, and Implementing Regulation (EU) 2023/1773 set penalties of €10 to €50 per tonne of unreported emissions. The definitive period (from January 2026) added the carbon cost. Comparing responses across these stages helps to distinguish the effects of expectations, compliance costs and carbon pricing.

We use the full monthly record of EU imports at the eight-digit Combined Nomenclature (CN8) level from Eurostat's Comext database, January 2019 to June 2026, aggregated to quarterly exporter-by-product cells. Treatment is assigned from the legal list of covered goods in Annex I of the Regulation. The control group consists of non-covered products in the same HS chapters, such as ferro-alloys, ferrous scrap, other inorganic chemicals and downstream articles of steel and aluminium. We estimate Poisson pseudo-maximum-likelihood (PPML) models (Santos Silva and Tenreyro, 2006) with exporter-by-product, exporter-by-quarter and chapter-by-quarter fixed effects, so that the effects are identified from differences between covered and non-covered products exported by the same country in the same quarter.

Our results can be summarised as follows. First, there is no evidence that covered imports fell during the proposal, adoption or reporting stages. The point estimates are positive, partly because the 2022 energy crisis raised EU demand for imported energy-intensive materials. Second, the sharpest response is anticipatory. In the last quarter before carbon costs applied, imports of covered goods rose by about 22 per cent relative to the first three quarters of 2025, and they fell by about 7 per cent in the first half of 2026. Monthly estimates show the surge concentrated in October and December 2025 and a reversal in February and March 2026. Steel, fertilisers and cement all show this pattern. Third, the estimate for the definitive period depends on how pre-existing trends are handled: it is close to zero in the baseline but between − 17 and − 23 per cent when we allow for a covered-product trend or restrict the controls to energy-intensive products. In 2026, covered exports from below-median-income countries fell by about 25 per cent relative to those from richer exporters.

The paper contributes to three literatures. It adds to the empirical literature on carbon leakage, which has mostly studied the EU ETS and found little evidence of leakage (Naegele and Zaklan, 2019; Dechezleprêtre and Sato, 2017), by examining the border instrument designed to prevent it. It complements the simulation literature on border carbon adjustments (Böhringer et al., 2012; Branger and Quirion, 2014; Clausing and Wolfram, 2023) with ex post evidence. And it contributes to the literature on how trade responds to anticipated policy changes (Handley and Limão, 2017; Khan and Khederlarian, 2021), showing that importers retime shipments around an anticipated carbon cost in much the same way as they do around scheduled tariff changes.

The rest of the paper is organised as follows. Section 2 describes the policy. Section 3 reviews the literature. Section 4 presents the data, Section 5 the empirical strategy and Section 6 the results. Section 7 reports robustness checks, Section 8 discusses the findings and Section 9 concludes.

2. Policy background

The European Commission proposed CBAM on 14 July 2021 as part of the “Fit for 55” package. After negotiations between the Council and Parliament, Regulation (EU) 2023/956 was adopted in May 2023 and published in the Official Journal on 16 May 2023. It covers six product groups listed in Annex I: cement, electricity, fertilisers, iron and steel, aluminium and hydrogen. Coverage is defined by CN codes. Most of Chap. 72 is covered, but ferrous scrap (heading 7204) and several ferro-alloys are not; in Chap. 73 only certain articles (headings 7301–7311, 7318 and 7326) are covered; and in Chap. 76, aluminium scrap (7602) and household articles (7615) are excluded. This product-level definition provides the treatment and control groups used in this paper.

CBAM was introduced in stages, summarised in Table 1. During the transitional period from 1 October 2023 to 31 December 2025, importers were required to submit quarterly reports on the direct and indirect emissions embedded in their imports. Implementing Regulation (EU) 2023/1773 set out the reporting rules and penalties of €10 to €50 per tonne of unreported emissions. No carbon price was charged, but the reporting obligation required importers to obtain verified data from foreign installations, which imposed costs on both sides of the transaction.

The definitive period began on 1 January 2026. From then on, imports of covered goods give rise to an obligation to surrender CBAM certificates, priced in line with the EU ETS, for the emissions embedded in them, net of any carbon price paid in the country of production. Regulation (EU) 2025/2083, published in October 2025, simplified the regime. It introduced an annual de minimis threshold of 50 tonnes per importer for iron and steel, aluminium, fertilisers and cement, and set 1 February 2027 as the start of certificate sales, with the first surrender for 2026 imports due in 2027. The carbon cost of 2026 imports was therefore certain, but its payment was deferred. Importers could avoid the charge entirely only by clearing goods through customs before January 2026, which gave them a clear incentive to bring shipments forward.

Table 1
Stages of CBAM used in the analysis

Stage	Dates in the sample	Event	Obligation on importers
Pre-period	2019Q1–2021Q2	—	None
Proposal	2021Q3–2023Q1	Commission proposal, 14 July 2021	None (expectations)
Adoption	2023Q2–2023Q3	Regulation (EU) 2023/956 adopted, May 2023	None (legal certainty)
Reporting phase	2023Q4–2025Q4	Transitional period from 1 October 2023	Quarterly emissions reports; penalties for non-reporting
Definitive period	2026Q1–2026Q2	Definitive period from 1 January 2026	Liability for CBAM certificates on embedded emissions

Sources

Regulation (EU) 2023/956; Implementing Regulation (EU) 2023/1773; Regulation (EU) 2025/2083.

Two other policies affected the same goods during the sample period. Since 2019 the EU has applied a safeguard to steel imports in the form of tariff-rate quotas. On 7 October 2025 the Commission proposed replacing it, when it expires at the end of June 2026, with a measure that would cut tariff-free quotas by 47 per cent and raise the out-of-quota duty to 50 per cent. In addition, the EU restricted imports of steel products from Russia and Belarus after February 2022, and later of aluminium products from Russia. We exclude Russia, Belarus and Ukraine from the baseline sample and discuss the steel measure when interpreting the results.

3. Literature review

3.1 Carbon leakage and border carbon adjustment in theory and simulation

Unilateral carbon pricing raises costs for domestic producers of emission-intensive goods and may shift production and emissions abroad. Copeland and Taylor (2004) review the theory of trade and the environment and the pollution haven hypothesis on which leakage concerns rest. Border carbon adjustments aim to level the playing field by charging imports for their embedded emissions. Elliott et al. (2010) show that a carbon tax applied to the carbon content of imports can capture a large share of global emissions. Fischer and Fox (2012) compare border adjustments with output-based rebates and find that border adjustments are more effective in reducing leakage, although their welfare effects depend on market structure.

A large simulation literature quantifies these effects. The Energy Modeling Forum study summarised by Böhringer et al. (2012) finds that border carbon adjustments reduce leakage, typically by around a third, while shifting part of the cost of climate policy to exporting countries. A meta-analysis by Branger and Quirion (2014) reaches similar conclusions about the reduction in leakage. Larch and Wanner (2017), using a structural gravity model, find that carbon tariffs reduce leakage but impose welfare losses on developing exporters. For the EU's proposal itself, Zhong and Pei (2022) estimate that CBAM would reduce exports of covered goods from trading partners and lower their welfare, with the largest effects on carbon-intensive producers. Mattoo et al. (2009) warn that border adjustments based on the carbon content of imports could cause large losses for manufacturing exports from developing countries. Clausing and Wolfram (2023) discuss the design of border adjustments when climate policies differ across countries and the risk of subsidy races.

3.2 Empirical evidence on leakage and competitiveness

Ex post evidence on carbon leakage, mostly from the EU ETS, points to modest effects. Naegele and Zaklan (2019) find no evidence that the EU ETS caused carbon leakage in European manufacturing

through trade flows in its first phases. Dechezleprêtre and Sato (2017) review the evidence on environmental regulation and competitiveness and conclude that effects on trade and investment have been small, partly because carbon prices were low and free allocation was generous. Fowlie et al. (2016) show, however, that leakage can be substantial in concentrated industries such as cement once market structure and dynamics are taken into account. Because CBAM is a new instrument, ex post evidence on its effects is still scarce.

3.3 Trade responses to anticipated policy

A separate literature shows that trade responds to policy before it takes effect. Handley and Limão (2017) show that reducing uncertainty about future tariffs increases trade. Khan and Khederlarian (2021) find that imports into the United States fell before scheduled NAFTA tariff reductions and rose after them, as importers delayed shipments to benefit from lower tariffs. CBAM's definitive period is an anticipated increase in the cost of importing certain goods, with a known start date, so the same incentive to shift shipments forward should apply.

3.4 Contribution

To our knowledge, this paper is among the first to estimate the trade effects of CBAM ex post, using official monthly import data that include the first half of the definitive period. It is also the first to separate the effects of the policy's stages and to test for front-loading before the carbon cost took effect.

4. Data

4.1 Trade data

Our source is Eurostat's Comext dataset DS-045409, "EU trade since 1988 by HS2-4-6 and CN8". We downloaded monthly imports of the EU27 (reporter EU27_2020, flow = imports) from every partner country through the Eurostat SDMX 2.1 application programming interface on 15 October 2026. The dataset had last been updated on 15 September 2026. We retrieved two indicators, value in euros and quantity in hundreds of kilograms, for every CN8 code in HS Chaps. 25 (salt, earths, stone and cement), 28 (inorganic chemicals, including hydrogen and ammonia), 31 (fertilisers), 72 (iron and steel), 73 (articles of iron or steel) and 76 (aluminium) from January 2019 to the latest month. July 2026 was incomplete at the time of download, so the sample ends in June 2026.

We keep extra-EU partner countries only, excluding EU member states, regional aggregates and unspecified territories. To neutralise annual revisions of the CN, we aggregate CN8 codes to the six-digit HS level. The exception is heading 2507, where only CN 2507 00 80 (other kaolinic clays) is covered and is kept separately. Monthly values are aggregated to quarters for the main analysis. We construct a balanced panel of all exporter-by-product pairs with positive imports in the pre-period (2019Q1–2021Q2), including zero flows in later quarters, which retains exits from the EU market in the sample.

Electricity is excluded because it is traded through grid interconnections with neighbouring countries and is not comparable with goods trade.

4.2 Treatment assignment

A product is treated if it falls within Annex I of Regulation (EU) 2023/956. In the downloaded chapters this covers cement and cement clinker (2523 and 2507 00 80); nitric acid, ammonia, potassium nitrates and nitrogenous and mixed fertilisers (2808, 2814, 2834 21, 3102, and 3105 except 3105 60); hydrogen (2804 10); iron and steel (Chap. 72 except ferrous scrap and the excluded ferro-alloys in 7202, together with headings 7301–7311, 7318 and 7326); and aluminium (7601, 7603–7614 and 7616). Iron ore pellets (2601 12) fall outside the downloaded chapters and are not included. We checked that coverage is uniform within every product unit. Table 2 shows the composition of the sample. Of 593 product units, 282 are covered, mainly iron and steel. Before the proposal, covered goods accounted for about €57 billion of annual EU imports from the sample countries, against €25 billion for the controls.

Table 2
Sample composition

Product group	Product units	Annual imports 2019Q1–2021Q2 (EUR bn)
Iron and steel	223	36.62
Aluminium	32	17.65
Fertilisers	20	2.56
Cement	6	0.37
Hydrogen	1	0.00
Non-covered products (controls)	311	24.72
Notes: Product units are HS6 codes (CN8 for 2507 00 80). Imports are annualised averages over 2019Q1–2021Q2 from the 200 sample exporters (excluding Russia, Belarus and Ukraine).		

Imports of covered goods are concentrated among a few exporters (Table 3). China, Türkiye, the United Kingdom and India together supplied over 40 per cent of covered imports over the sample period. Some lower-income economies are also important suppliers: Egypt ranks tenth and Viet Nam just outside the top ten, which is relevant for the heterogeneity analysis in Section 6.6.

Table 3
Main exporters of CBAM-covered goods to the EU

Exporter	Share of covered imports, 2019Q1–2026Q2 (%)
China	17.7
Türkiye	11.5
United Kingdom	7.9
India	6.6
Norway	6.4
Korea, Rep.	4.9
Switzerland	4.7
Taiwan	4.3
United States	4.0
Egypt	2.5

4.3 Exporter characteristics

To test whether the response differs across exporters, we use two pre-determined characteristics from the Our World in Data (OWID) CO2 dataset, averaged over 2017–2019. The first is carbon dioxide emissions per unit of primary energy, a measure of the carbon intensity of the exporter's energy system, which we use as a rough proxy for the carbon intensity of its industrial production. The second is real GDP per capita. We classify exporters as high carbon intensity or below-median income relative to the sample median (the income median is about 9,700 international dollars). Thirty small partners lack OWID data and are dropped from the heterogeneity analysis.

4.4 Descriptive evidence

Figure 1 plots the value of EU imports of covered and non-covered products, indexed to 2019. Both series rose sharply in 2021–2022 as commodity prices and EU energy costs surged, then fell back in 2023. The two series move closely together for most of the period. There are two exceptions. Covered imports fell relative to the controls in 2020, during the pandemic, and recovered during 2021. They also rose sharply in 2025Q4 and fell in 2026Q1, whereas non-covered imports fell in 2025Q4 and rose in 2026Q1.

5. Empirical strategy

5.1 Staged difference-in-differences

Let denote EU imports from exporter of product in quarter. We estimate

where equals one for covered products and indicates the four stages in Table 1: proposal, adoption, reporting and definitive. The exporter-by-product fixed effects absorb time-invariant determinants of trade in each product from each country. The exporter-by-quarter effects absorb everything that affects a country's exports to the EU as a whole in a given quarter, including exchange rates, demand shocks, trade agreements and country-level sanctions. The chapter-by-quarter effects absorb shocks common to all products within an HS chapter, such as changes in steel or aluminium prices and in EU demand for each type of material. The coefficients therefore measure the change in imports of covered products relative to non-covered products of the same chapter, from the same exporter, in each stage relative to the pre-period. Under PPML, is the proportional change.

We estimate Eq. (1) by PPML, which handles zero trade flows and is consistent under heteroskedasticity (Santos Silva and Tenreyro, 2006; Yotov et al., 2016), using the high-dimensional fixed effects algorithm of Correia et al. (2020) as implemented in the Python package pyfixest. Standard errors are clustered by product, the level at which treatment is assigned.

5.2 Event study and front-loading

To examine dynamics and pre-trends, we replace the stage indicators with interactions between and a dummy for each quarter, omitting 2021Q2, the last quarter before the proposal:

To test for front-loading before the definitive period, we use monthly data for January 2024 to June 2026 and estimate Eq. (2) at monthly frequency, with June 2025 as the reference month. We then estimate a pooled version for January 2025 to June 2026 with two indicators: October–December 2025 and January–June 2026, with January–September 2025 as the reference. Front-loading implies a positive coefficient on the first and a negative coefficient on the second.

5.3 Identification

The key assumption is that, without CBAM, imports of covered and non-covered products from the same exporter would have followed parallel paths after accounting for the fixed effects. The main threats are shocks that affect covered products differently from other products in the same chapter. Three are important. The 2022 energy crisis raised EU production costs for energy-intensive materials, which are disproportionately covered. The steel safeguard and its proposed replacement affect only steel. Pandemic-era disruptions in 2020 hit covered products harder than other products in the same chapters. We assess these threats with the event-study pre-trends, by adding a covered-product linear trend (Freyaldenhoven et al., 2019), by isolating the energy-crisis window, and by restricting the control group to energy-intensive non-covered products: ferro-alloys, ferrous scrap, other inorganic chemicals and non-covered fertilisers. Because tests for pre-trends have limited power and can distort subsequent inference (Roth, 2022; Rambachan and Roth, 2023), we report several specifications rather than a single preferred one.

6. Results

6.1 Staged estimates

Table 4 reports the baseline estimates. In column (1), none of the stages is associated with a decline in covered imports. The coefficients are positive for the proposal (0.052), adoption (0.102) and reporting (0.101, p = 0.08) stages and close to zero for the definitive period (0.012). The quantity estimates in column (2) are larger and significant for the adoption (0.254) and reporting (0.234) stages, implying that the volume of covered imports grew by about 26–29 per cent relative to controls during those stages. Since unit values within exporter–product pairs were stable (Section 6.4), the gap between columns (1) and (2) more likely reflects a shift in the product mix towards heavier, lower-value covered goods than a change in prices. With only quarter fixed effects (column 3) all coefficients are small and insignificant, and two-way clustering by exporter and product (column 4) widens the confidence intervals. Including Russia, Belarus and Ukraine (column 5) makes the reporting coefficient larger and significant (0.139). Trade with these countries after 2022 was shaped mainly by sanctions and war, which is why they are excluded from the baseline.

Table 4
Staged effects of CBAM on EU imports (PPML)

CBAM × Proposal (2021Q3–2023Q1)	**(1) Value**	**(2) Quantity**	**(3) Quarter FE**	**(4) Two-way cluster**	**(5) Incl. RU/BY/UA**
	0.052	**0.089**	**0.004**	**0.052**	**0.074**
	(0.046)	(0.078)	(0.084)	(0.047)	(0.047)
CBAM × Adoption (2023Q2–Q3)	0.102	0.254***	0.027	0.102	0.117*
	(0.066)	(0.091)	(0.123)	(0.088)	(0.061)
CBAM × Reporting phase (2023Q4–2025Q4)	0.101*	0.234**	0.033	0.101	0.139**
	(0.058)	(0.096)	(0.076)	(0.069)	(0.058)
CBAM × Definitive period (2026Q1–Q2)	0.012	0.027	−0.050	0.012	0.041
	(0.077)	(0.125)	(0.083)	(0.094)	(0.078)
Observations	622,424	614,978	622,424	622,424	657,914

Notes: Dependent variable: quarterly EU import value (columns 1, 3, 4, 5) or quantity in 100 kg (column 2) by exporter and product, 2019Q1–2026Q2. All columns include exporter×product and exporter×quarter fixed effects; columns (1), (2), (4) and (5) also include HS chapter×quarter fixed effects, and column (3) quarter fixed effects instead. Standard errors clustered by product (two-way by exporter and product in column 4) in parentheses. Columns (1)–(4) exclude Russia, Belarus and Ukraine. *** p < 0.01, ** p < 0.05, * p < 0.10.

6.2 Event study

Figure 2 plots the quarterly event-study coefficients. First, the pre-period is not flat. Covered imports were relatively high in 2019 and fell relative to controls through 2020, reaching − 0.075 in 2021Q1. A joint Wald test rejects the null hypothesis that all nine pre-period coefficients are zero (Wald statistic 23.8, p = 0.005), and a placebo treatment dated 2020Q3 within the pre-period yields a coefficient of − 0.090 (p = 0.03). Covered imports therefore fell relative to the controls during 2020 and only partly recovered before the proposal, largely because the pandemic hit steel and aluminium trade harder than trade in other materials. Second, covered imports rose relative to controls in 2022Q3–2022Q4, at the peak of the energy crisis, when EU producers of steel, aluminium and fertilisers curtailed output because of high gas and electricity prices. Third, the largest coefficient in the sample is in 2025Q4 (0.332, p = 0.001), the last quarter before the definitive period, followed by a drop to 0.015 in 2026Q1.

6.3 Front-loading before the definitive period

Figure 3 zooms in on January 2024 to June 2026 at monthly frequency. Coefficients fluctuate around zero through September 2025. They then rise to 0.238 in October 2025 (p = 0.008) and 0.352 in December 2025 (p = 0.001), and become negative in February (− 0.174, p = 0.006) and March 2026 (− 0.149, p = 0.013). The pattern is what one would expect if importers brought shipments forward to clear customs before carbon costs applied.

Table 5 and Fig. 4 report the pooled front-loading estimates. Relative to January–September 2025, covered imports were 0.196 log points higher in October–December 2025 (about 22 per cent, p < 0.001) and 0.075 log points lower in January–June 2026 (about 7 per cent, p = 0.04). The difference between the two coefficients is highly significant (p < 0.001). Front-loading is statistically significant in three of the four sectors. Steel imports rose by 0.139 before the deadline and fell by 0.086 after it, both significant. Fertilisers (0.348) and cement (0.252) show large and significant front-loading, followed by negative but imprecise post-deadline coefficients. Aluminium shows the same signs, but neither coefficient is significant.

Table 5
Front-loading before the definitive period (monthly PPML, January 2025–June 2026)

CBAM × Oct–Dec 2025	All covered	Iron and steel	Aluminium	Fertilisers	Cement
	0.196* **	**0.139*** **	**0.102**	**0.348** **	**0.252*** **
	(0.054)	(0.043)	(0.079)	(0.151)	(0.085)
CBAM × Jan–Jun 2026	−0.075**	−0.086**	−0.021	−0.122	−0.149
	(0.037)	(0.042)	(0.135)	(0.095)	(0.110)
Observations	268,276	233,100	150,348	131,984	129,197

Notes: Dependent variable: monthly EU import value by exporter and product. Reference period: January–September 2025. Fixed effects: exporter×product, exporter×month and HS chapter×month. Sector columns compare each sector's covered products with all non-covered products. Standard errors clustered by product in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.10.

The steel safeguard is a possible alternative explanation for the steel results, but it cannot explain the overall pattern. The Commission's proposal of 7 October 2025 would tighten steel quotas only from July 2026, which would encourage importers to bring steel forward into the first half of 2026, not into late 2025. If anything, the safeguard proposal should have raised steel imports in early 2026, which works against the decline we observe. In addition, fertilisers and cement, which are not subject to the steel measure, show front-loading of similar or larger size.

6.4 Margins of adjustment

Table 6 shows how imports adjusted. The probability that an exporter-product pair records positive trade did not change in any stage (coefficients between − 0.009 and 0.002), so CBAM has not yet caused exporters to exit the EU market. Unit values were also unchanged, with coefficients below 0.02 in absolute value in every stage. The front-loading and the movements in the staged estimates therefore reflect changes in quantities shipped by existing suppliers rather than entry, exit or price changes.

Table 6
Extensive margin and unit values

CBAM × Proposal (2021Q3–2023Q1)	**P(trade > 0), LPM**	**Log unit value, OLS**
	−0.009	**0.001**
	(0.006)	(0.024)
CBAM × Adoption (2023Q2–Q3)	−0.003	0.003
	(0.007)	(0.029)
CBAM × Reporting phase (2023Q4–2025Q4)	0.002	−0.007
	(0.007)	(0.024)
CBAM × Definitive period (2026Q1–Q2)	0.002	0.017
	(0.008)	(0.031)
Observations	627,720	312,342

Notes: Column (1): linear probability model for positive imports; column (2): OLS on log unit value (euros per 100 kg) for positive flows. Fixed effects as in Table 4, column (1). Standard errors clustered by product. *** p < 0.01, ** p < 0.05, * p < 0.10.

6.5 Sectors

Table 7 reports the staged estimates separately for each sector. Iron and steel, which dominates the covered sample, follows the aggregate pattern, with positive coefficients in the adoption (0.151, p = 0.04) and reporting (0.120, p = 0.09) stages and none in the definitive period. Aluminium shows no significant effect at any stage. Fertilisers show a negative adoption coefficient (− 0.296, p = 0.07) and no later effect. Cement imports increased relative to controls in every stage, by 0.26 to 0.56 log points. Cement comprises only six product units with volatile trade, and the positive estimates appear from the proposal stage onward, before any obligation applied. We therefore do not interpret them as effects of CBAM.

Table 7
Staged effects by sector

CBAM × Proposal (2021Q3–2023Q1)	Iron and steel	Aluminium	Fertilisers	Cement
	0.027	**0.041**	**0.311**	**0.263***
	(0.039)	(0.157)	(0.217)	(0.138)
CBAM × Adoption (2023Q2–Q3)	0.151**	0.175	−0.296*	0.451***
	(0.072)	(0.157)	(0.166)	(0.106)
CBAM × Reporting phase (2023Q4–2025Q4)	0.120*	−0.041	0.052	0.557***
	(0.071)	(0.104)	(0.136)	(0.119)
CBAM × Definitive period (2026Q1–Q2)	0.019	−0.052	−0.063	0.454**
	(0.087)	(0.245)	(0.188)	(0.197)
Observations	544,773	346,179	308,870	302,622

Notes: Each column compares the covered products of one sector with all non-covered products. Specification as in Table 4, column (1). *** p < 0.01, ** p < 0.05, * p < 0.10.

6.6 Heterogeneity across exporters

Table 8 tests whether the effects differ by exporter characteristics. The exporter-by-quarter fixed effects absorb all country-level differences, so the interactions are identified from differences between covered and non-covered products within exporters. Exporters with high carbon intensity increased their covered exports relative to others during the adoption (0.248, p = 0.02) and reporting (0.158, p = 0.05) stages, but there is no difference in the definitive period. Lower-income exporters also expanded during the adoption stage (0.367, p = 0.03). In the definitive period, however, their covered exports fell by 0.291 log points relative to higher-income exporters (p = 0.04), a relative decline of about 25 per cent. This is the first indication in the data that the carbon-cost stage may be weighing more heavily on lower-income exporters, although it rests on only two quarters of observations.

Table 8
Heterogeneity by exporter carbon intensity and income

CBAM × Proposal (2021Q3–2023Q1)	**Group = high carbon intensity**	**Group = below-median income**
	−0.001	**0.048**
	(0.067)	(0.049)
CBAM × Adoption (2023Q2–Q3)	−0.037	0.070
	(0.092)	(0.070)
CBAM × Reporting phase (2023Q4–2025Q4)	0.012	0.094
	(0.071)	(0.060)
CBAM × Definitive period (2026Q1–Q2)	0.017	0.037
	(0.101)	(0.078)
× Proposal × Group	0.096	0.061
	(0.070)	(0.141)
× Adoption × Group	0.248**	0.367**
	(0.106)	(0.168)
× Reporting × Group	0.158**	0.094
	(0.080)	(0.128)
× Definitive × Group	−0.001	−0.291**
	(0.096)	(0.143)
Observations	580,270	580,270

Notes: “Group” is an indicator for exporters above the median CO2 emissions per unit of primary energy (column 1) or below the median real GDP per capita (column 2), both averaged over 2017–2019 from the OWID CO2 dataset. Group main effects are absorbed by exporter×quarter fixed effects. Specification otherwise as in Table 4, column (1). *** p < 0.01, ** p < 0.05, * p < 0.10.

7. Robustness

Table 9 reports four robustness checks that address the identification threats discussed in Section 5.3.

Table 9
Robustness

CBAM × Proposal (2021Q3–2023Q1)	(a) CBAM trend	(b) Energy-intensive controls	(c) Energy window	(d) 2025Q4 separated
	−0.021	**0.002**	**−0.020**	**0.052**
	(0.045)	(0.103)	(0.040)	(0.046)
CBAM × Adoption (2023Q2–Q3)	−0.008	−0.207*	0.102	0.102
	(0.079)	(0.109)	(0.066)	(0.066)
CBAM × Reporting phase (2023Q4–2025Q4)	−0.055	−0.093	0.101*	
	(0.077)	(0.079)	(0.058)	
CBAM × Reporting phase excl. 2025Q4				0.076
				(0.058)
CBAM × 2025Q4				0.298***
				(0.089)
CBAM × Definitive period (2026Q1–Q2)	−0.190*	−0.260**	0.012	0.012
	(0.099)	(0.128)	(0.077)	(0.077)
CBAM × linear trend	0.008**			
	(0.004)			
CBAM × Energy-crisis window (2022Q3–2023Q1)			0.166***	
			(0.060)	
Observations	622,424	456,957	622,424	622,424

Notes: PPML with exporter×product, exporter×quarter and HS chapter×quarter fixed effects; standard errors clustered by product. (a) adds a linear trend interacted with CBAM coverage; (b) restricts the controls to ferro-alloys and ferrous scrap (7202, 7204), inorganic chemicals (Chap. 28) and non-covered fertilisers; (c) adds an indicator for covered products in 2022Q3–2023Q1; (d) separates 2025Q4 from the rest of the reporting phase. *** p < 0.01, ** p < 0.05, * p < 0.10.

Pre-trends. Adding a covered-product linear trend (column a) removes the positive coefficients in the earlier stages, which become small and insignificant, and yields a definitive-period coefficient of − 0.190 (p = 0.056), a decline of about 17 per cent relative to trend. The trend itself is small and positive (0.008

per quarter). Because extrapolating a linear trend over seven years is a strong assumption, this estimate is best read as the upper end of the plausible range for the decline.

Energy-intensive controls. When the control group is restricted to energy-intensive products that were also affected by the energy crisis but are not covered by CBAM (column b), the definitive-period coefficient is − 0.260 (p = 0.04), about 23 per cent, and the adoption coefficient becomes negative (− 0.207, p = 0.06). This comparison addresses the concern that covered products were exposed to the energy crisis more than the full control group.

Energy crisis. Isolating 2022Q3–2023Q1 (column c) confirms that covered imports rose by 0.166 log points (about 18 per cent, p = 0.005) during the energy crisis, and reduces the proposal-stage coefficient to − 0.020. The small and insignificant positive proposal-stage estimate in the baseline therefore reflects the energy crisis rather than CBAM.

Front-loading at quarterly frequency. Separating 2025Q4 from the reporting phase (column d) gives a 2025Q4 coefficient of 0.298 (about 35 per cent, p < 0.001) and reduces the remaining reporting-phase coefficient to 0.076, which is no longer significant. The weakly positive reporting-phase effect in the baseline is thus largely explained by front-loading at the end of the phase.

Two further checks are reported in Table 4. Results are similar with quarter rather than chapter-by-quarter fixed effects (column 3), and two-way clustering by exporter and product does not change the conclusions (column 4).

8. Discussion

8.1 Why imports did not fall before 2026

The absence of a decline before 2026 is consistent with the design of the reporting phase. Without a carbon price, the main cost to importers was administrative. For most importers, these costs were plausibly small relative to the value of the goods and easier to absorb than a switch to EU suppliers, whose own costs had risen with energy prices. The relative increase in covered imports during the energy crisis is a reminder that the EU's demand for imported basic materials depends heavily on its own production costs, which CBAM does not affect.

8.2 Front-loading as evidence of expected costs

The surge at the end of 2025 is the most robust result. It shows that importers expected the definitive period to raise the cost of covered goods by enough to justify holding additional inventories, despite the deferral of certificate purchases to 2027 and the exemption of small importers. Front-loading is costly. It requires financing, storage and a willingness to bear price risk, so the size of the response is an indirect measure of the expected carbon cost. Shipments are known to be retimed around anticipated tariff changes (Khan and Khederlarian, 2021), and our results suggest that traders respond to a carbon border charge much as they do to a tariff.

Front-loading also complicates the evaluation of CBAM. Imports in the first months of 2026 were depressed partly because inventories had been built up in late 2025. The negative coefficient for January–June 2026 therefore combines a genuine effect of the carbon cost with a temporary reversal of front-loading. Separating the two will require data for later in 2026 and 2027, once inventories have been run down and certificates are actually purchased.

8.3 Distributional implications

The 2026 decline is larger for lower-income exporters. This is consistent with concerns raised in the simulation literature (Mattoo et al., 2009; Larch and Wanner, 2017) that border adjustments fall disproportionately on developing countries. Two mechanisms are plausible. Lower-income exporters are less able to provide verified installation-level emissions data, so their goods are more likely to be assessed at default values, which are designed to be conservative. They are also less likely to have domestic carbon prices that can be deducted from the CBAM charge. By contrast, we find no difference by carbon intensity in the definitive period, which suggests that, so far, the cost of compliance has mattered more than actual carbon content. This interpretation is tentative, since our carbon-intensity measure refers to the energy system as a whole, not to the exporting installations.

8.4 Limitations

The evidence is preliminary. Our sample covers only the first two quarters of the definitive period. Although the liability arises at the time of import, certificates for 2026 imports can be bought only from February 2027, and the CBAM charge is being phased in gradually as free allocation under the EU ETS is phased out. The effective carbon cost in our sample is therefore still well below its long-run level. Early responses may also reflect the new authorisation requirement for importers above the 50-tonne annual threshold rather than carbon pricing. The threshold also means that not all covered imports are subject to the charge. Covered imports fell relative to the controls early in the pre-period, and the definitive-period estimate ranges from about + 1 per cent to about − 23 per cent depending on how this pattern is handled (Tables 4 and 9). Our control products come from the same chapters as the covered products, and some of them, such as downstream steel articles outside Annex I, may be substitutes for covered goods. Our estimates would overestimate the reduction of covered imports and the embedded emissions if importers were to switch to these products to avoid CBAM. Only EU imports are observed. We do not assess whether exporters redirected covered goods, or their more carbon-intensive production, to other markets; UN Comtrade data for the later months of 2026 would allow this question to be examined. Finally, CBAM coverage is defined at the CN8 level, whereas our product units are HS6 codes. We verified that coverage is uniform within each HS6 unit; the only exception is heading 2507, which we keep at the CN8 level.

9. Conclusion and policy implications

This paper has provided early evidence on how EU imports responded to the stages of the Carbon Border Adjustment Mechanism, using official monthly trade data through June 2026. Imports of covered goods

did not fall when the policy was proposed, adopted or put into its reporting phase. The clearest response came at the end of 2025, when importers brought forward shipments of steel, fertilisers and cement to avoid the carbon cost that applied from January 2026. Imports then fell in the first half of 2026. The size of the decline in the definitive period depends on how pre-existing trends are handled, but it is larger for lower-income exporters, and there is no sign yet of exits from the EU market or of changes in prices.

The findings have three implications. First, evaluations of CBAM must account for anticipation. Comparisons of 2026 with 2025 will overstate the effect of the carbon cost if they ignore the front-loading at the end of 2025. Second, the reporting phase does not appear to have been a barrier to trade on its own, which suggests that the administrative burden alone did not deter trade. Third, the early signs that lower-income exporters are more affected support targeted assistance, such as help with emissions monitoring and verification, and support for domestic carbon pricing, which would allow exporters to deduct carbon costs paid at home. If the larger effect on lower-income exporters reflects their greater reliance on default values, the ability to document actual emissions may become an important source of competitiveness under CBAM.

Future research should extend the analysis as more data become available, examine trade diversion to non-EU markets, and use firm- or installation-level data to distinguish the cost of compliance from the cost of carbon.

Declarations

Author Contribution

J.I. conceived the study, designed the empirical strategy, collected and processed the Eurostat data, and carried out the econometric analysis. M.N. reviewed the literature, contributed to the interpretation of the results, and prepared the tables and figures. J.I. wrote the main manuscript text, and M.N. revised it critically for important intellectual content. All authors reviewed and approved the final manuscript.

Acknowledgement

Not applicable

Data Availability

Data is available from authors on request

References

1. Böhringer C, Balistreri EJ, Rutherford TF (2012) The role of border carbon adjustment in unilateral climate policy: Overview of an Energy Modeling Forum study (EMF 29). Energy Econ 34(S2):S97–

S110. https://doi.org/10.1016/j.eneco.2012.10.003

2. Branger F, Quirion P (2014) Would border carbon adjustments prevent carbon leakage and heavy industry competitiveness losses? Insights from a meta-analysis of recent economic studies. Ecol Econ 99:29–39. https://doi.org/10.1016/j.ecolecon.2013.12.010
3. Clausing KA, Wolfram C (2023) Carbon border adjustments, climate clubs, and subsidy races when climate policies vary. J Economic Perspect 37(3):137–162. https://doi.org/10.1257/jep.37.3.137
4. Copeland BR, Taylor MS (2004) Trade, growth, and the environment. J Econ Lit 42(1):7–71. https://doi.org/10.1257/002205104773558047
5. Correia S, Guimarães P, Zylkin T (2020) Fast Poisson estimation with high-dimensional fixed effects. Stata J 20(1):95–115. https://doi.org/10.1177/1536867X20909691
6. Dechezleprêtre A, Sato M (2017) The impacts of environmental regulations on competitiveness. Rev Environ Econ Policy 11(2):183–206. https://doi.org/10.1093/reep/rex013
7. Elliott J, Foster I, Kortum S, Munson T, Pérez Cervantes F, Weisbach D (2010) Trade and carbon taxes. Am Econ Rev 100(2):465–469. https://doi.org/10.1257/aer.100.2.465
8. Eurostat (2026) *EU trade since 1988 by HS2-4-6 and CN8*(DS-045409) [Data set]. Comext database. Retrieved October 15, 2026, from https://ec.europa.eu/eurostat/databrowser/view/DS-045409/default/table?lang=en
9. European Union (2023a) Regulation (EU) 2023/956 of the European Parliament and of the Council of 10 May 2023 establishing a carbon border adjustment mechanism. Official J Eur Union, *L 130*, 16.5.2023. https://eur-lex.europa.eu/eli/reg/2023/956/oj
10. European Union (2023b) Commission Implementing Regulation (EU) 2023/1773 of 17 August 2023 laying down the rules for the application of Regulation (EU) 2023/956 as regards reporting obligations during the transitional period. *Official Journal of the European Union, L 228*, 15.9.2023. https://eur-lex.europa.eu/eli/reg_impl/2023/1773/oj
11. European Union (2025) Regulation (EU) 2025/2083 of the European Parliament and of the Council of 8 October 2025 amending Regulation (EU) 2023/956 as regards simplifying and strengthening the carbon border adjustment mechanism. Official J Eur Union, L series, 17.10.2025. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ:L_202502083
12. Fischer C, Fox AK (2012) Comparing policies to combat emissions leakage: Border carbon adjustments versus rebates. J Environ Econ Manag 64(2):199–216. https://doi.org/10.1016/j.jeem.2012.01.005
13. Fowlie M, Reguant M, Ryan SP (2016) Market-based emissions regulation and industry dynamics. J Polit Econ 124(1):249–302. https://doi.org/10.1086/684484
14. Freyaldenhoven S, Hansen C, Shapiro JM (2019) Pre-event trends in the panel event-study design. Am Econ Rev 109(9):3307–3338. https://doi.org/10.1257/aer.20180609
15. Handley K, Limão N (2017) Policy uncertainty, trade, and welfare: Theory and evidence for China and the United States. Am Econ Rev 107(9):2731–2783. https://doi.org/10.1257/aer.20141419

16. Khan SS, Khederlarian A (2021) How does trade respond to anticipated tariff changes? Evidence from NAFTA. J Int Econ 133:103538. https://doi.org/10.1016/j.jinteco.2021.103538
17. Larch M, Wanner J (2017) Carbon tariffs: An analysis of the trade, welfare, and emission effects. J Int Econ 109:195–213. https://doi.org/10.1016/j.jinteco.2017.09.003
18. Mattoo A, Subramanian A, van der Mensbrugghe D, He J (2009) *Reconciling climate change and trade policy*(Policy Research Working Paper No. 5123). World Bank. https://ideas.repec.org/p/wbk/wbrwps/5123.html
19. Naegele H, Zaklan A (2019) Does the EU ETS cause carbon leakage in European manufacturing? J Environ Econ Manag 93:125–147. https://doi.org/10.1016/j.jeem.2018.11.004
20. Rambachan A, Roth J (2023) A more credible approach to parallel trends. Rev Econ Stud 90(5):2555–2591. https://doi.org/10.1093/restud/rdad018
21. Roth J (2022) Pretest with caution: Event-study estimates after testing for parallel trends. Am Economic Review: Insights 4(3):305–322. https://doi.org/10.1257/aeri.20210236
22. Santos Silva JMC, Tenreyro S (2006) The log of gravity. Rev Econ Stat 88(4):641–658. https://doi.org/10.1162/rest.88.4.641
23. Yotov YV, Piermartini R, Monteiro J-A, Larch M (2016) *An advanced guide to trade policy analysis: The structural gravity model*. World Trade Organization and United Nations Conference on Trade and Development. https://doi.org/10.30875/abc0167e-en
24. Zhong J, Pei J (2022) Beggar thy neighbor? On the competitiveness and welfare impacts of the EU's proposed carbon border adjustment mechanism. Energy Policy 162:112802. https://doi.org/10.1016/j.enpol.2022.112802

Figures

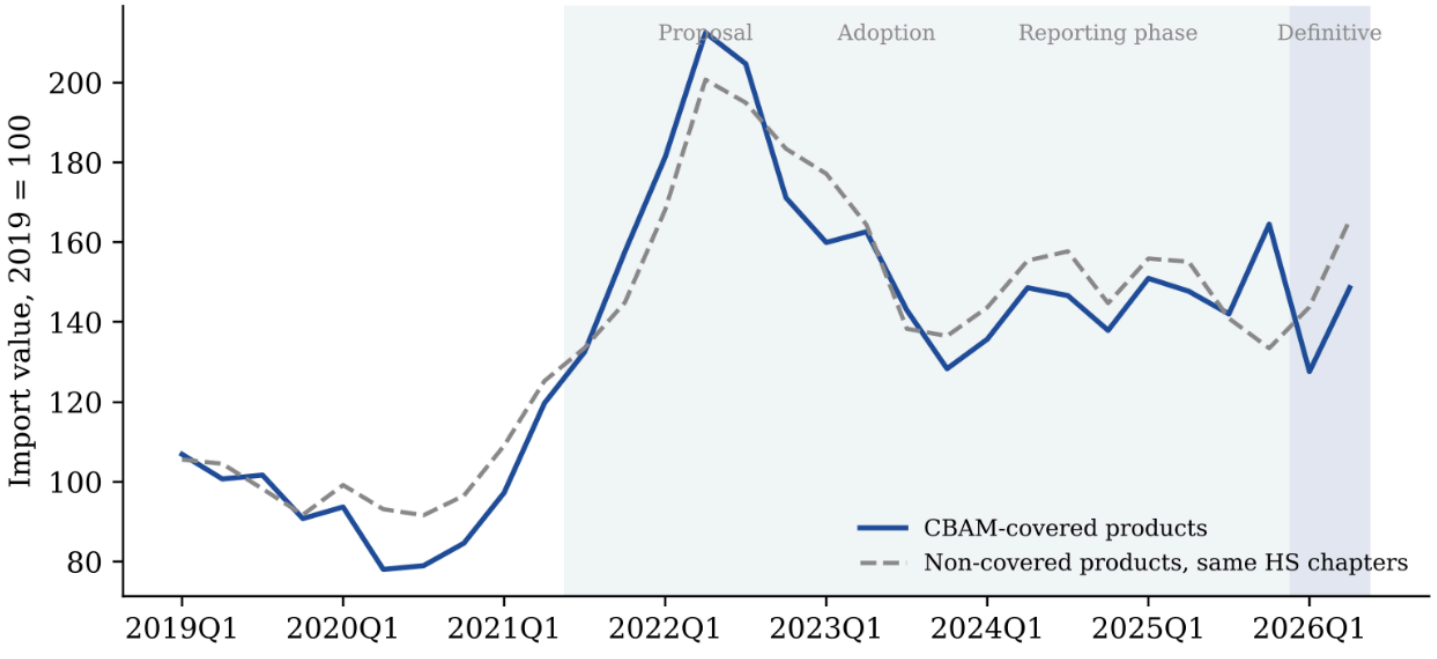


Figure 1

EU imports of CBAM-covered and non-covered products, 2019Q1–2026Q2 (value, 2019 = 100). Shaded areas mark the CBAM stages. Source: Eurostat Comext DS-045409; author's calculations.

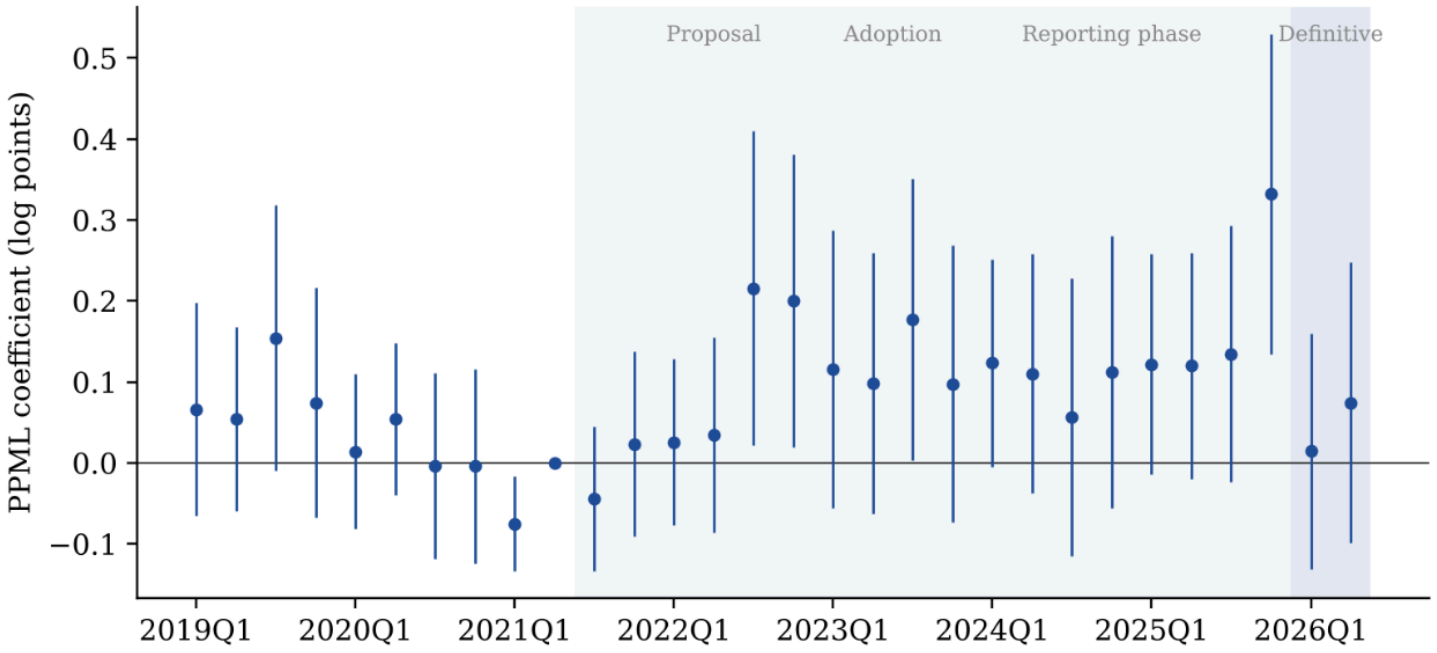


Figure 2

Event study: CBAM-covered versus non-covered imports by quarter (reference 2021Q2). PPML coefficients with 95 per cent confidence intervals; fixed effects as in Table 4, column (1). Source: author's estimates.

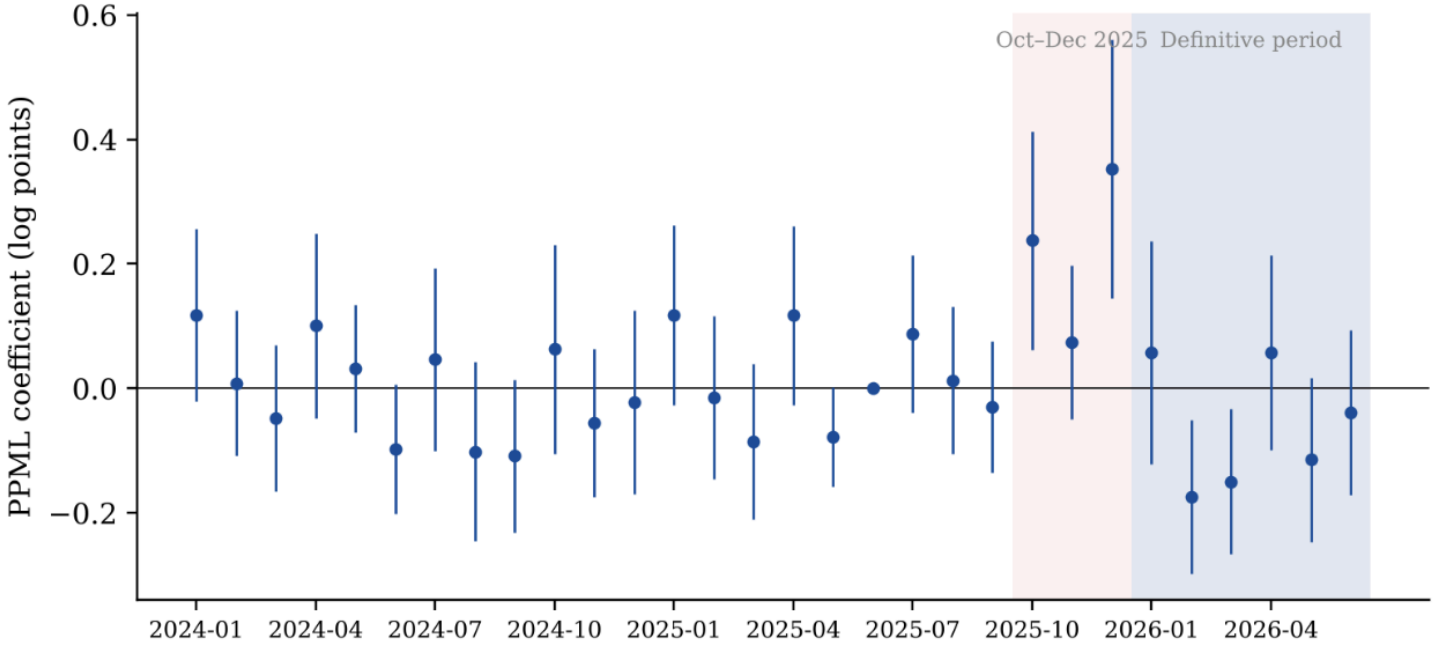


Figure 3

Monthly event study around the start of the definitive period, January 2024–June 2026 (reference June 2025). PPML coefficients with 95 per cent confidence intervals; exporter×product, exporter×month and chapter×month fixed effects. Source: author's estimates.

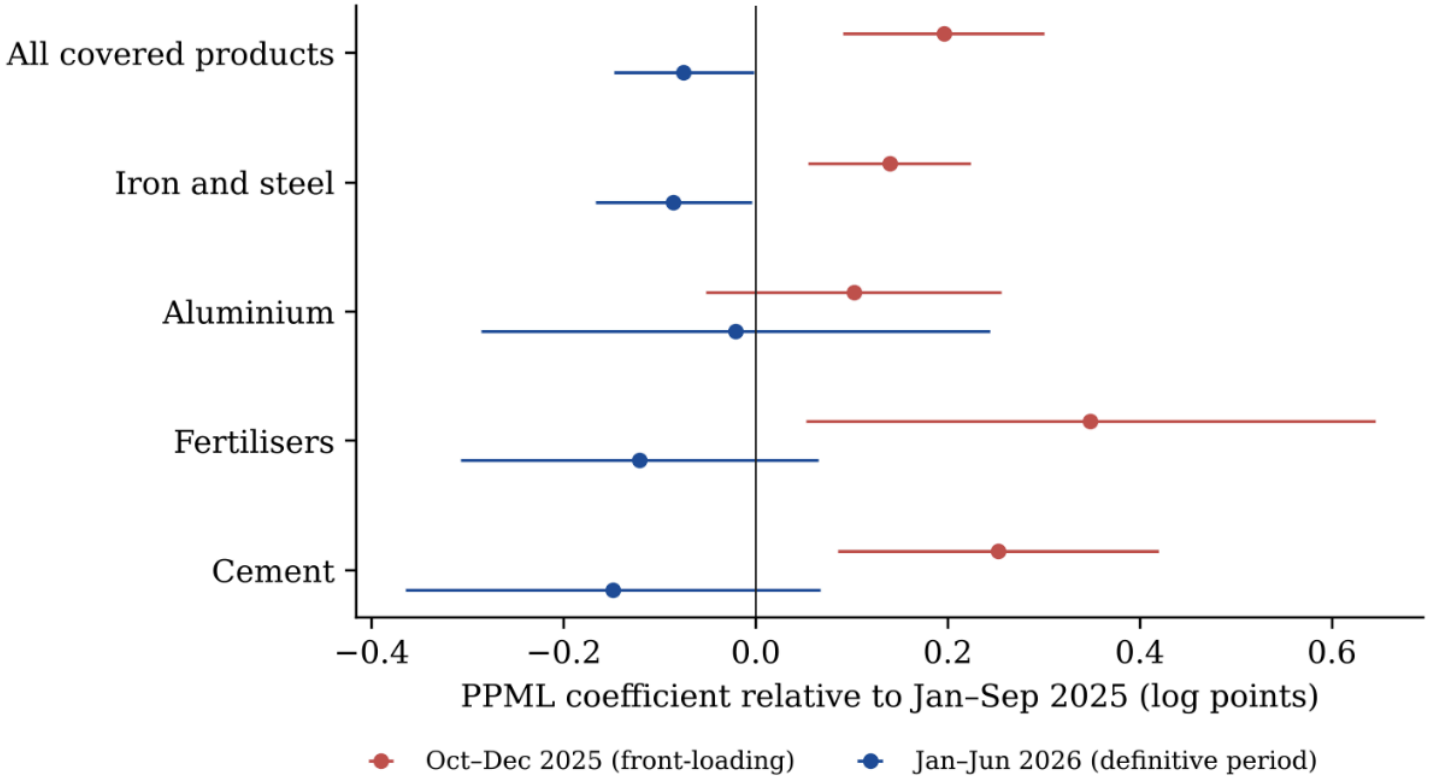


Figure 4

Front-loading and post-deadline effects by sector. PPML coefficients relative to January–September 2025, with 95 per cent confidence intervals. Source: author's estimates.