Designing Effective Border Adjustment with Minimal Information Requirements: Theory and Evidence

Alessia Campolmi
University of Verona

joint with Chiara Forlati, Harald Fadinger, Sabine Stillger and Ulrich Wagner

4th Banca d'Italia, European Central Bank and World Bank Conference on
"Trade, value chains and financial linkages in the global economy"

December 15-16, 2025

Climate Change Mitigation Policy and Carbon Leakage

In **2015**, 196 countries negotiate the **Paris Accord:** Emission should be cut by roughly **50%** by **2030** and should reach **net-zero** by **2050**.

Yet, in 2024 only 25% of Greenhouse gas (GHG) emissions worldwide are subject to carbon taxes or cap-and-trade policies (World Bank, 2024)

Countries tackle this target at different speeds ⇒ significant risk of carbon leakage (i.e., production displacement abroad)

2021: EU initiates a legislative process to increase ambition behind pricing emissions while preventing leakage through a carbon border adjustment mechanism (CBAM)

- Changes the paradigm that trade policy cannot be used to enforce climate policy

CBAM: Carbon Border Adjustment Mechanism

Main objectives

1. Deter carbon leakage to third countries
2. Provide incentive for CO_2 emissions reductions abroad

(3. Encourage adoption of carbon pricing or equivalent policies in non-EU countries)

How does it work?

- Calculate CO_2 emissions embedded in imports from non-EU countries (*actual* emissions of production plant in origin country)
- Buy CBAM certificates for each ton of imported embedded emissions
- CBAM certificates have same price as Emissions Trading System (ETS) allowances

CBAM levels playing field w.r.t carbon costs:

import tax depends on carbon intensity and carbon pricing in foreign countries

CBAM - The perfect is the enemy of the good

- Because of high information needs, CBAM initially applies only to few sectors: aluminum steel, cement, fertilizers, hydrogen and electricity
  $\Rightarrow$ distorts production across and within sectors (e.g. offshore production of final goods that use carbon-intensive intermediates)
- Moral hazard: Costly monitoring needed to sanction under-reporting
- CBAM discriminates imported goods depending on their carbon footprints
  $\Rightarrow$ political opposition from carbon-intensive exporting countries that would face high CBAM rates (mostly low-income)
  $\Rightarrow$ it may require an exemption from WTO's Most Favored Nation principle

This paper

- High **ambitions** behind CBAM threaten its feasibility.
- We propose a alternative border adjustment mechanism that focuses on leakage prevention: the Leakage Border Adjustment Mechanism
- We build quantitative trade model to compare how CBAM, LBAM and other border adjustment mechanisms affect carbon leakage, trade and welfare

An Alternative Proposal to CBAM

LBAM (Leakage Border Adjustment Mechanism)

LBAM gives up the goal of reducing foreign emissions and concentrates on eliminating leakage.

Recall what is driving carbon leakage:

Higher EU carbon price:

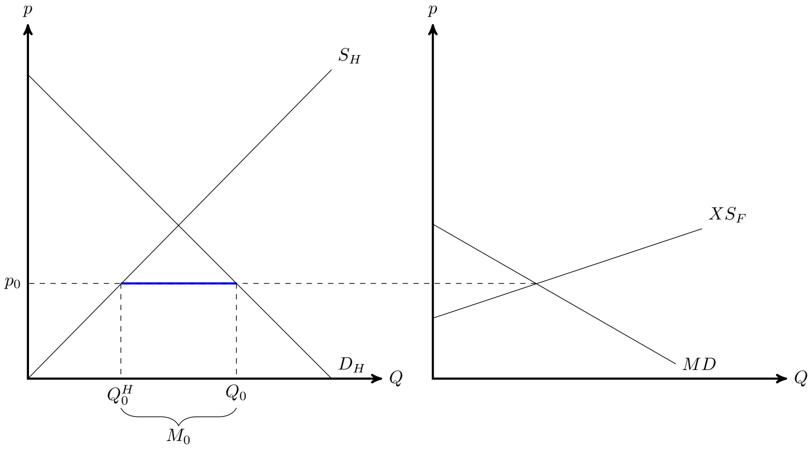
- shifts upward the EU supply of carbon intensive products
- increases demand for imported substitutes and reduces EU exports

$\Rightarrow$ **Emissions leakage due to**:
CO_2 embedded in increased imports to the EU and increased exports between third countries

LBAM: designed to exactly offset the change in imports and exports induced by EU ETS $\Rightarrow$ exact leakage offset

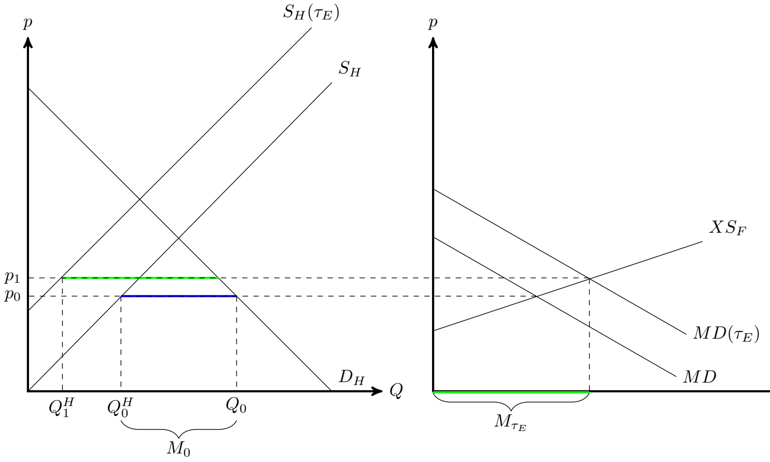
Carbon Leakage: Higher imports M_{τ_E} due to carbon price τ_E

Simple model with home (H) and foreign (F) country



Carbon Leakage: Higher imports M_{τ_E} due to carbon price τ_E

Simple model with home (H) and foreign (F) country

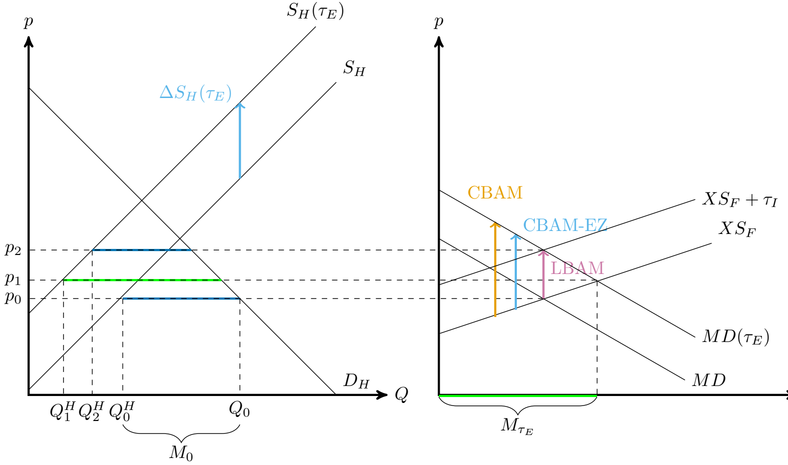


Carbon price τ_E is introduced in H

- Domestic supply S_H shifts out to $S_H(\tau)$
- Import demand MD_H shifts out to $MD_H(\tau)$
- International price increases from p_0 to p_1
- Leakage: Increase in import demand $\Delta M = M_{\tau_e} - M_0$

LBAM tariff τ_I resets imports to M_0: Zero Leakage

Home charges LBAM tariff τ_I



- Drives a wedge between import demand MD_H and export supply XS_F
- Consumer price increases from p_1 to p_2, world price drops to p_0
- More domestic supply, reduction in imports by $-\Delta M$: leakage undone

Information requirements for a feasible policy proposal

1. Theoretical model of international trade to derive LBAM rates from first principles and analyze effects on welfare and emissions
2. Empirical estimates and parameters needed to calibrate LBAM tariffs
   - Import demand elasticities and returns to scale
   - Elasticity of output to carbon emissions and physical input in H
   - Expenditure shares

   All these objects can be estimated using readily available data

   $\Rightarrow$ no additional bureaucracy needed

   $\Rightarrow$ border adjustment can be introduced in all sectors

Preview of Main Results

1. Any Border Adjustment Mechanism (BAM) should be designed so that it can be applied to *all* sectors. Limiting BAMs to a handful of sectors leaves much carbon leakage intact.
2. A simple CBAM that taxes embedded emissions in imports using EU carbon intensities performs almost as good as the exact CBAM in terms of emissions and welfare, but with substantially lower admin costs.
3. However, both CBAM variants have major trade impacts and put significant abatement burden on non-EU countries.
4. In contrast, LBAM can address both import and export leakage with low information requirements and minimal trade impacts.

Theoretical Framework

Quantitative trade model

- Multi-country model with trade in differentiated products and many sectors
- Quasi-linear utility, Cobb-Douglas aggregation of sectoral CES bundles
- Within each sector, a fixed number of firms produce differentiated varieties and compete under monopolistic competition
- Production functions are market-specific with sector-specific returns to scale
- Firms use a physical input and energy to produce
- The price of the physical input is normalized to one due to a freely traded outside good with linear technology
- The price of energy is exogenously given (no energy price leakage)
- Carbon emissions are a by-product of energy input and are a global bad

Demand

- ▷ Utility

$$U_i = C_{i0} + \int_s \eta_{is} \log C_{is} d_s - \theta_i \int_s e_s ds,$$

$$C_{is} = \left[\sum_{j=1}^{J} \int_0^{N_{ijs}} c_{ijs}(\omega)^{\frac{\varepsilon_s - 1}{\varepsilon_s}} d\omega \right]^{\frac{\varepsilon_s}{\varepsilon_s - 1}}$$

  - C_{i0} is the tradable good in country i
  - $c_{ijs}(\omega)$ is the consumption by country i of an individual sector-s variety ω produced in country j
  - e_s denotes global emissions from sector s with social marginal cost θ_i

$\Rightarrow$Consumers derive utility from consumption and disutility from global emissions

- ▷ Associated demand functions

$$c_{ijs}(\omega) = \left(\frac{p_{ijs}(\omega)}{P_{ijs}} \right)^{-\varepsilon_s} C_{ijs} \qquad C_{ijs} = \left(\frac{P_{ijs}}{P_{is}} \right)^{-\varepsilon_s} \eta_{is} P_{is}^{-1}$$

Production

- Monopolistic competition, fixed number of firms N_{ijs}
- Production of country j for market i in sector s has variable returns to scale

$$y_{ijs} = \phi_{ijs} \left(\frac{z_{ijs}}{\beta_s}\right)^{\beta_s} \left(\frac{l_{ijs}}{\alpha_s}\right)^{\alpha_s}$$

  - z_{ijs} is the energy use associated with the production
  - l_{ijs} is a composite physical input (factors other than energy)
  - ϕ_{ijs} is a productivity shifter.
- Associated marginal cost function:

$$MC_{ijs} = \left(\frac{y_{ijs}}{\phi_{ijs}}\right)^{\gamma_s} p_{Zj}^{\beta_s(1+\gamma_s)} \phi_{ijs}^{-1}$$

where $\gamma_s \equiv 1/(\alpha_s + \beta_s) - 1$ represents the returns to scale

Carbon Emissions and Carbon Tax

- Carbon emissions embodied in goods produced by sector s in country j for market i are given by

$$e_{ijs} = d_j z_{ijs}$$

where d_j denotes the rate of carbon emissions per unit of energy in country j.

- Assume a tax of τ_{Ej} dollars per unit of carbon emissions. Then the unit cost of energy gross of the carbon tax is given by:

$$p_{Zj} = \tilde{p}_{Zj} + d_j \tau_{Ej}$$

.

where $\tilde{p}_{Zj}$ is the energy price in country j net of carbon taxes

Sectoral Equilibrium

Closed-form solution for y_{ijs}, p_{ijs} and P_{is} for all i, j and s:

$$y_{ijs} = \left(\eta_{is}\tau_{ijs}^{1-\varepsilon_s}\right)^{\frac{1}{\gamma_s\varepsilon_s+1}} \left(\phi_{ijs} p_{Zj}^{-\beta_s}\right)^{\frac{(\gamma_s+1)\varepsilon_s}{\gamma_s\varepsilon_s+1}} \left(\mu_s \tau_{Iijs}\tau_{Xijs}\right)^{\frac{-\varepsilon_s}{\gamma_s\varepsilon_s+1}} P_{is}^{\frac{\varepsilon_s-1}{\gamma_s\varepsilon_s+1}}$$

and

$$p_{ijs} = \eta_{is}^{\frac{\gamma_s}{\gamma_s\varepsilon_s+1}} \left(\tau_{ijs}\phi_{ijs}^{-1} p_{Zj}^{\beta_s}\right)^{\frac{\gamma_s+1}{\gamma_s\varepsilon_s+1}} \left(\mu_s \tau_{Iijs}\tau_{Xijs}\right)^{\frac{1}{\gamma_s\varepsilon_s+1}} P_{is}^{\frac{\gamma_s(\varepsilon_s-1)}{\gamma_s\varepsilon_s+1}}$$

where

$$P_{is}^{\frac{(\gamma_s+1)(1-\varepsilon_s)}{\gamma_s\varepsilon_s+1}} = \sum_{j=1}^{J} N_{ijs} \left(\eta_{is}^{\frac{\gamma_s}{\gamma_s\varepsilon_s+1}} \left(\tau_{ijs}\phi_{ijs}^{-1} p_{Zj}^{\beta_s}\right)^{\frac{\gamma_s+1}{\gamma_s\varepsilon_s+1}} \left(\mu_s \tau_{Iijs}\tau_{Xijs}\right)^{\frac{1}{\gamma_s\varepsilon_s+1}}\right)^{1-\varepsilon_s}$$

Equilibrium in Changes

- Define $\hat{X} \equiv \frac{X'}{X}$.
- Then energy price changes in response to a change in carbon price: $\hat{p}_{Zj} = \frac{\tilde{p}_{Zj} + d_j \hat{\tau}_{Ej} \tau_{Ej}}{\tilde{p}_{Zj} + d_j \tau_{Ej}}$
- Responses of equilibrium variables:

$$\hat{y}_{ijs} = \hat{p}_{Zj}^{-\beta_s \frac{(\gamma_s+1)\varepsilon_s}{\gamma_s \varepsilon_s + 1}} \left(\hat{\tau}_{Iijs} \hat{\tau}_{Xijs}\right)^{\frac{-\varepsilon_s}{\gamma_s \varepsilon_s + 1}} \hat{P}_{is}^{\frac{\varepsilon_s - 1}{\gamma_s \varepsilon_s + 1}}$$

$$\hat{p}_{ijs} = \hat{p}_{Zj}^{\beta_s \frac{\gamma_s + 1}{\gamma_s \varepsilon_s + 1}} \left(\hat{\tau}_{Iijs} \hat{\tau}_{Xijs}\right)^{\frac{1}{\gamma_s \varepsilon_s + 1}} \hat{P}_{is}^{\frac{\gamma_s(\varepsilon_s - 1)}{\gamma_s \varepsilon_s + 1}}$$

$$\hat{P}_{is}^{\frac{(1+\gamma_s)(1-\varepsilon_s)}{\gamma_s \varepsilon_s + 1}} = \sum_{j=1}^{J} \delta_{ijs} \hat{p}_{Zj}^{\beta_s \frac{(\gamma_s+1)(1-\varepsilon_s)}{\gamma_s \varepsilon_s + 1}} \left(\hat{\tau}_{Iijs} \hat{\tau}_{Xijs}\right)^{\frac{1-\varepsilon_s}{\gamma_s \varepsilon_s + 1}},$$

which can be computed given

- δ_{ijs} the bilateral expenditure shares of country i on goods produced by country j.
- ε_s the sectoral demand elasticities and γ_s the returns to scale parameters
- α_s and β_s the output elasticities
- the changes in energy prices $\hat{p}_{Zj}$ tariffs $\hat{\tau}_{Iijs}$ and exports taxes $\hat{\tau}_{Xijs}$

No-BAM: A unilateral carbon-price increase without border adjustment

- Response of home sales to domestic market:

$$\hat{y}_{iis} = \hat{p}_{Zi}^{\frac{-\beta_s \ (\gamma_s+1)\varepsilon_s}{1+\varepsilon_s\gamma_s}} \left[\delta_{iis}\hat{p}_{Zi}^{\frac{\beta_s(1+\gamma_s)(1-\varepsilon_s)}{1+\varepsilon_s\gamma_s}} + 1 - \delta_{iis}\right]^{\frac{-1}{1+\gamma_s}} < 1.$$

- Domestic import response:

$$\hat{y}_{ijs} = \left[\delta_{iis}\hat{p}_{Zi}^{\frac{\beta_s(1+\gamma_s)(1-\varepsilon_s)}{1+\varepsilon_s\gamma_s}} + 1 - \delta_{iis}\right]^{\frac{-1}{1+\gamma_s}} > 1$$

- Domestic export response:

$$\hat{y}_{jis} = \hat{p}_{Zi}^{\frac{-\beta_s \ (\gamma_s+1)\varepsilon_s}{1+\varepsilon_s\gamma_s}} \left[\delta_{jis}\hat{p}_{Zi}^{\frac{\beta_s(1+\gamma_s)(1-\varepsilon_s)}{1+\varepsilon_s\gamma_s}} + 1 - \delta_{jis}\right]^{\frac{-1}{1+\gamma_s}} < 1$$

CBAM tariff

- CBAM tariff emulates the effect of imposing Home's carbon tax in Foreign's export sector on energy prices $\hat{p}_{Zij} = 1 + \frac{d_j \tau \hat{E}_i \tau_{E_i}}{p_{Z_j}}$ and pass-through:

$$\hat{\tau}_{Iijs} = \hat{p}_{Zij}^{\beta_s(\gamma_s+1)}$$

in CBAM sectors and $\hat{\tau}_{Iijs} = 1$ elsewhere.

- Under this policy scheme the equilibrium responses are

$$\hat{y}_{ijs} = \hat{p}_{Zij}^{\frac{-\beta_s(\gamma_s+1)\varepsilon_s}{\gamma_s\varepsilon_s+1}} \hat{P}_{is}^{\frac{\varepsilon_s-1}{\gamma_s\varepsilon_s+1}}$$

$$\hat{p}_{ijs} = \hat{p}_{Zij}^{\frac{\beta_s(\gamma_s+1)}{\gamma_s\varepsilon_s+1}} \hat{P}_{is}^{\frac{\gamma_s(\varepsilon_s-1)}{\gamma_s\varepsilon_s+1}}$$

$$\hat{P}_{is}^{\frac{(1+\gamma_s)(1-\varepsilon_s)}{\gamma_s\varepsilon_s+1}} = \sum_{j=1}^{J} \delta_{ijs} \hat{p}_{Zij}^{\beta_s\frac{(\gamma_s+1)(1-\varepsilon_s)}{\gamma_s\varepsilon_s+1}} > 1$$

for all s covered by CBAM. $\hat{y}_{ijs} < 1$ in CBAM sectors if $dj > di$

LBAM Tariffs and Export Subsidies

- Holding aggregate imports constant without discrimination in response to a change in τ_{Ei} implies the following condition:

$$\hat{\tau}_{lis}^{\frac{-\varepsilon_s(1+\gamma_s)}{\gamma_s\varepsilon_s+1}} = \delta_{iis}\hat{p}_{Zi}^{\frac{\beta_s(\gamma_s+1)(1-\varepsilon_s)}{\gamma_s\varepsilon_s+1}} + (1-\delta_{iis})\hat{\tau}_{lis}^{\frac{1-\varepsilon_s}{\gamma_s\varepsilon_s+1}}$$

  with $\hat{\tau}_{lijs} = \hat{\tau}_{lis}\ \forall j$, i.e., LBAM tariffs are independent of the trade partner and hence non-discriminatory.
- Holding aggregate exports constant requires setting a non-discriminatory export subsidy equal to the pass-through

$$\hat{\tau}_{Xi} = \hat{p}_{Zi}^{-\beta_s(\gamma_s+1)} < 1$$

  i.e. also LBAM export subsidies are independent of the export destination

Calibration

Calibrating the model

- Model has 131 sectors, consists of the EU and 56 other countries
  - Estimate import demand elasticities and returns to scale (export supply elasticities) using 4-digit product-level import data for the EU (Soderbery, 2015) more
  - Estimate elasticities of output to emissions and physical inputs at the 4-digit level from German firm-level micro data more
  - Compute expenditure shares at 4-digit level with product-level import data from COMTRADE and production data from UNIDO
  - Energy prices and carbon intensity from IEA and own data collection more
  - Social cost of carbon $\theta_i = 178$ Dollars per ton of CO_2 equivalent, based on the central estimate in Rennert et al. (2022), discounted back to 2018

Computing the effects of policies

For each border adjustment mechanism considered:

- Consider carbon price change from 15 to 105 Dollars (2018-2023).
- Compute discrete changes in EQ outcomes in response to an EU policy change relative to initial EQ calibrated on 2018 data

Border Adjustment Scenarios

EU unilaterally increases carbon price from 15$ to 105$ per tonne in all manufacturing

- **No-BAM** No border adjustment
- **CBAM-EU** Tax embedded emissions in imports of aluminium, steel, iron, fertilisers, cement
- **CBAM-ID** Tax emissions embedded in *all* imports (ideal CBAM)
- **CBAM-EZ** As CBAM-ID, but using EU carbon intensity to compute embedded emissions
- **LBAM** Tariffs on imports that eliminate bilateral import-related leakage in all sectors.
- **LBAM-X** In addition to tariffs, export subsidies that sterilise export-related leakage

Trade Impacts of different Border Adjustments

EU Imports with Different Border Adjustments

Table 1: % Change in EU Bilateral Imports when Carbon Price rises to $105

	Mean	Median	SD	Min	Max
No-BAM	11	0	35	0	305
CBAM-EU	10	0	35	-51	305
CBAM-ID	-8	-3	21	-100	482
CBAM-EZ	-8	-3	17	-100	253
LBAM, LBAM-X	0	0	0	0	0

- Unilateral carbon pricing shifts comparative advantage to non-EU producers
- EU CBAMs hardly prevent import leakage but hit hard in selected sectors.
- Ideal CBAMs overcompensate import leakage, *reducing* average imports by 8%.
- LBAMs reset bilateral imports to pre-policy levels.
- LBAM does not limit EU market access for its trading partners

EU Tariffs for Different Border Adjustments

Table 2: % Change in EU Import Tariffs when Carbon Price rises to $105

Scenario	**Mean**	**Median**	**SD**	**Min**	**Max**
No-BAM	0	0	0	0	0
CBAM-EU	0.3	0	1.7	0	39.2
CBAM-ID	8.3	5.7	8.8	0	105.6
CBAM-EZ	7.5	5.3	7.8	0.1	94.8
LBAM, LBAM-X	1.3	0.6	1.8	0	8.6

- Import tariffs needed to prevent carbon leakage (LBAM) are modest
- CBAM tariffs are significantly higher.

Export Leakage and the Case for Subsidies

Table 3: % Change in EU Exports and Export Subsidies when Carbon Price rises to $105

Scenario	**Mean**	**Median**	**SD**	**Min**	**Max**
A. EU Bilateral Exports					
No-BAM, CBAM-**, LBAM	-9.4	-2.9	15.4	-79.5	0
LBAM-X	0	0	0	0	0
B. EU Export subsidies					
No-BAM, CBAM-**, LBAM	0	0	0	0	0
LBAM-X	3.7	3.0	2.6	0.2	10.5

- Export leakage is economically significant and cannot be addressed by tariffs.
- LBAM-X addresses export leakage with relatively moderate export subsidies.

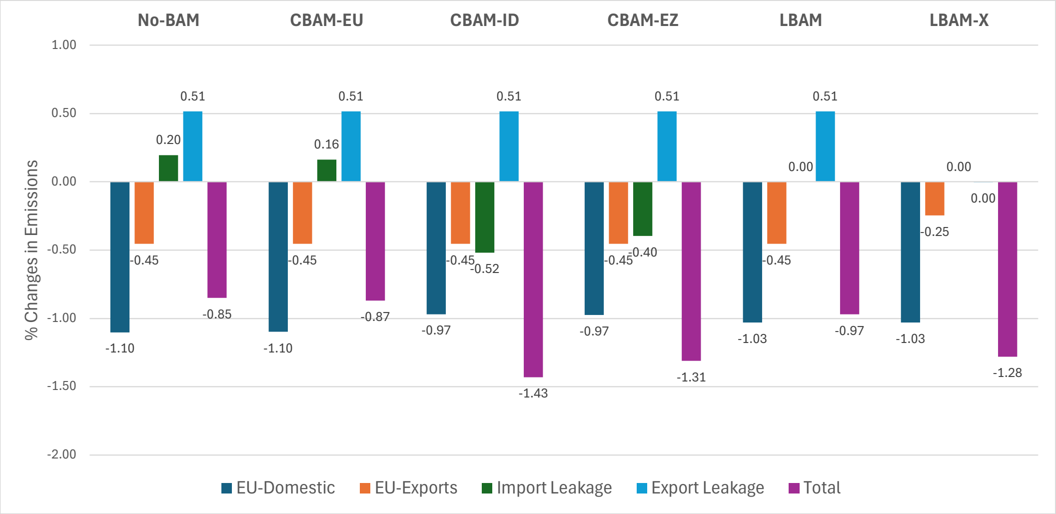
Emissions, Economic Costs and Welfare Impacts of Different Border Adjustments

Changes in EU and Global Emissions

	Δ Emissions (% of 2018 level)		Additional Reduction in Global Emissions (% of Reference)
	EU	Global	
No-BAM (Reference)	-29.2	-0.85	-
CBAM-EU	-29.1	-0.87	3.4
CBAM-ID	-26.7	-1.43	67.6
CBAM-EZ	-26.8	-1.31	54.0
LBAM	-27.9	-0.97	14.3
LBAM-X	-24.0	-1.28	49.8

- Carbon leakage: one out of every three tons
- Import leakage accounts for just 30% of this
- CBAM induces strong abatement in countries that export to the EU, but only if applied to all sectors.

Impact of EU Policy on Carbon Emissions



Impact of EU Carbon Price Increase on EU Economic Costs

	(i) Government Revenue	(ii) Consumer Surplus	(iii) Profits	(iv) Economic Costs = (i)+(ii)+(iii)
No-BAM	68.6	-101.7	-23.6	-56.7
CBAM-EU	70.4	-103.6	-22.7	-55.9
CBAM-ID	135.5	-151.8	-8.8	-25.1
CBAM-EZ	129.2	-146.4	-10.1	-27.2
LBAM	79.1	-112.1	-18.7	-51.6
LBAM-X	32.6	-112.1	27.3	-52.2

- Unilaterally increasing carbon prices imposes always economic costs for EU
- LBAM-X reduces economic costs by 10%
- Comprehensive CBAMs cuts EU economic costs by half

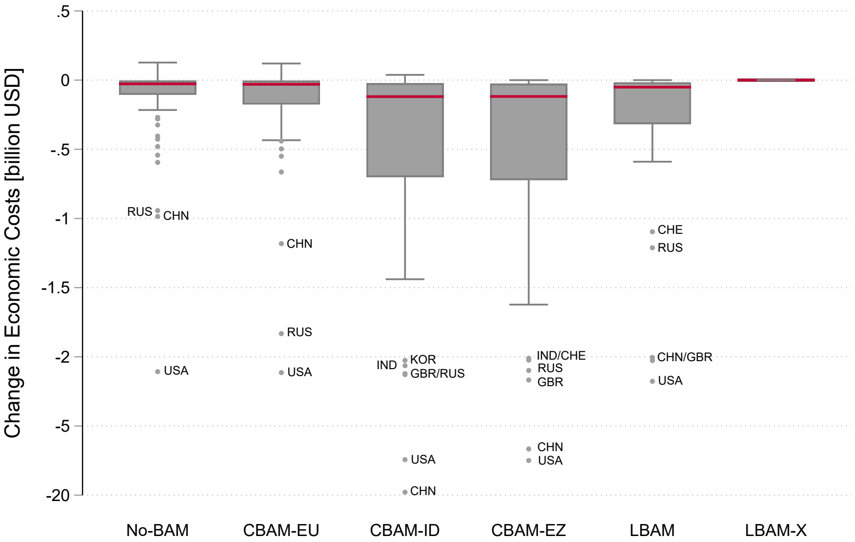
Impact of EU Carbon Price Increase on EU Welfare

	(iv) Economic Costs	(v) Environmental Benefit	(vi) Welfare = (iv) + (v)	(vii) Global Abatement [%]
No-BAM	-56.7	31.9	-24.9	0.85
CBAM-EU	-55.9	32.9	-23.0	0.87
CBAM-ID	-25.1	53.8	28.7	1.43
CBAM-EZ	-27.2	49.4	22.2	1.31
LBAM	-51.6	36.6	-15.1	0.97
LBAM-X	-52.2	48.1	-4.1	1.28

- ▷ Our benchmark calibration attributes the global environmental benefit entirely to the EU
- ▷ Under CBAMs the economic costs are more than compensated by the environmental benefits (but at expense of non-EU countries)
- ▷ LBAM-X yields almost the same emissions reductions as CBAM-EZ.
  $\Rightarrow$ on environmental grounds shifting abatement towards non-EU countries is not strictly necessary

Welfare Impacts on Foreign Countries

Distribution of Economic Costs across Non-EU Countries



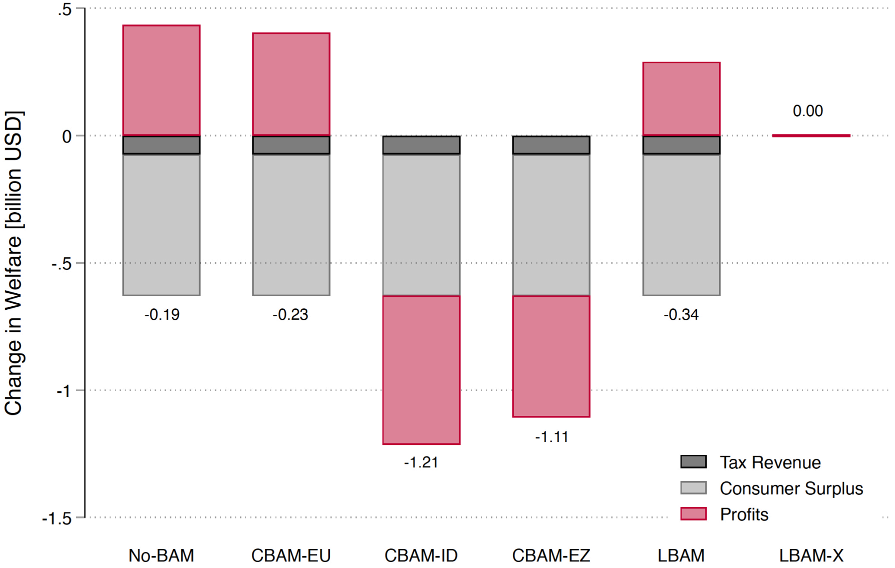
- **Negative effect**: Higher prices of EU exports induce a substitution effect in foreign markets
- **Positive effect**: Foreign domestic production becomes more competitive
- Under **CBAM-ID** and **-EZ** economic costs are large (up to 20bn for China)

Conclusion

- **BAMs** can **prevent carbon leakage** if applied to **all sectors**, not just to a few. Simple BAMs with **low information requirements** are easier to apply broadly.
- Among simple BAMs, those that minimize extra-territorial effects stand the best chances of **surviving WTO scrutiny** and avoiding diplomatic backlash
- **Comprehensive CBAMs** (ideal or simple) have strong, **detrimental trade impacts** on EU partners.
- **LBAM** *is a feasible alternative that deters carbon leakage without limiting EU market access*

Welfare Impacts on Foreign Countries

Decomposition of the Economic Costs for Non-EU Countries



- **Negative effect**: Higher prices of EU exports reduces consumer surplus and tax revenues
- **Positive effect**: Foreign domestic production becomes more competitive
  - **No-BAM and CBAM-EU:** Profits of domestic firms rise
  - **LBAM** Profits rise but not as much
  - **CBAM-ID and -EZ:** Profits fall

Robustness

Robustness Check

- Welfare results re-evaluated using country-specific SCC values. EU's SCC reduced from \$178 to \$71.
- Excluding outliers when computing trade and output elasticities.
- Capital stock estimated using Perpetual Inventory Method.
- CRS ($\gamma = 0$) and trade elasticity $\varepsilon = 6$ in all sectors.

Robustness Check: Country-Level SCC

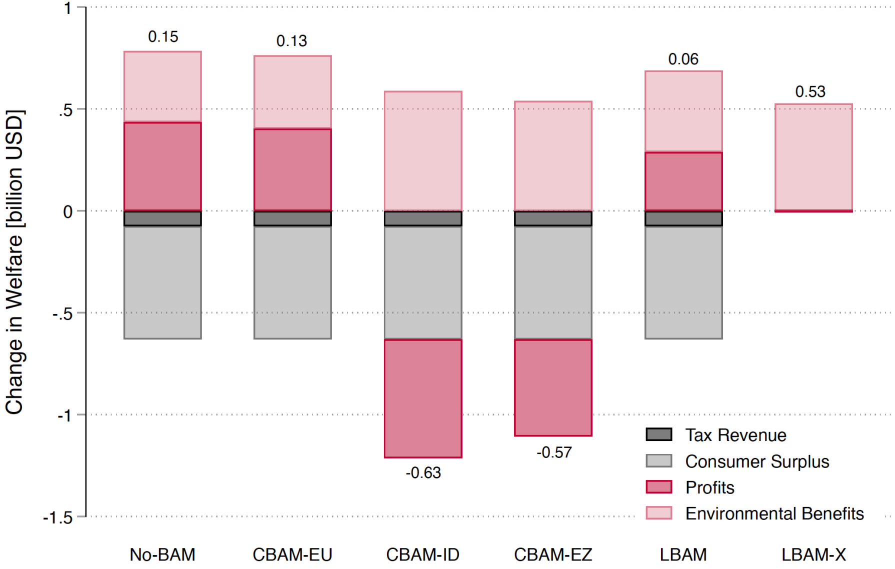
- Welfare results re-evaluated using country-specific SCC values.
- Disaggregation of global SCC is methodologically complex and debated.
- We follow Farrokhi & Lashkaripour (2025) who infer disutility from emissions using:
  - Environmental taxes,
  - Scaled by population and energy use.
- Country SCCs are adjusted to match our sample and the global SCC of \$178:
  - Exclude Turkey and Japan (not in our sample).
  - Assign unlisted countries to ‘Rest-of-World’ regional aggregates.
  - UK treated separately post-Brexit.
- Result: EU’s SCC reduced from \$178 to \$71.
- Implies 60% reduction in environmental benefit estimates for the EU.

Impact of EU Carbon Price Increase on EU Welfare

	(iv) Economic Costs	(v) Environmental Benefit	(vi) Welfare = (iv) + (v)	(vii) Global Abatement [%]
No-BAM	-56.7	12.7	-44.0	0.85
CBAM-EU	-55.9	13.1	-42.8	0.87
CBAM-ID	-25.1	21.4	-3.7	1.43
CBAM-EZ	-27.2	19.7	-7.5	1.31
LBAM	-51.6	14.6	-37.1	0.97
LBAM-X	-52.2	19.2	-33.0	1.28

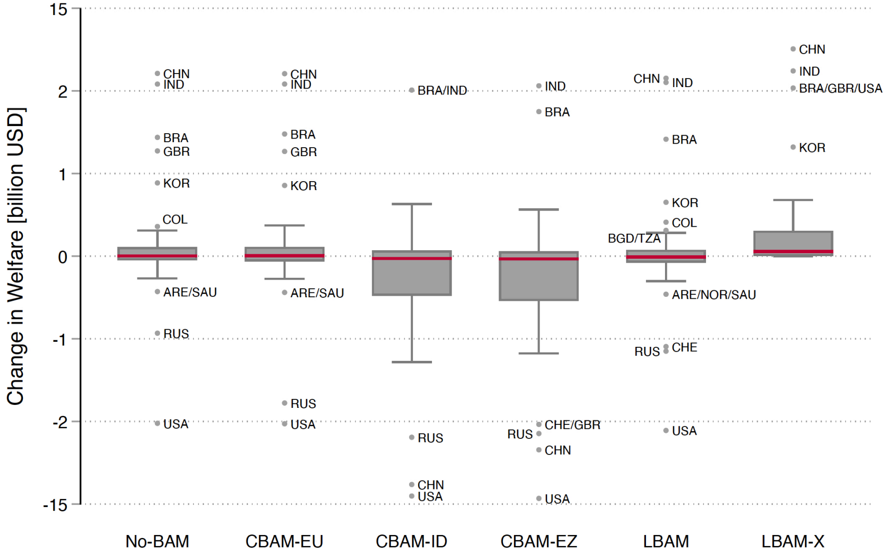
- ▷ The welfare effect for the EU turns negative across all scenarios, including for CBAM-ID and CBAM-EZ which previously delivered a welfare gain.
- ▷ The welfare ranking of scenarios is not affected ⇒ LBAMs still provide larger welfare than No-BAM or CBAM-EU.

Decomposition of Changes in Welfare for Non-EU Countries



- Non-EU countries benefit from assigning country-specific SCC estimates (i.e. they **value emission reduction**).
- Except under CBAM-ID and CBAM-EZ, **average welfare is positive** in all scenarios.

Distribution of Changes in Welfare across Non-EU Countries



- ▷ **CBAM-ID** and **CBAM-EZ**, still imply large welfare losses for many countries, in particular for the US and China
- ▷ Under **no-BAM, CBAM-EU** or **LBAM** countries either experience small welfare losses or small gains.
- ▷ **LBAM-X** now makes all foreign countries better off since they now value global emission reductions.

Impact of EU Carbon Price Increase on EU Welfare and Global Emissions

	(iv) Economic Costs	(v) Environmental Benefit	(vi) Welfare $= \text{(iv)} + \text{(v)}$	(vii) Global Abatement [%]
A. Excluding Outliers in Elasticities				
No-BAM	-54.8	36.3	-18.5	1.02
CBAM-EU	-54.0	37.4	-16.6	1.05
CBAM-ID	-30.1	49.3	19.2	1.39
CBAM-EZ	-31.7	46.8	15.1	1.32
LBAM	-50.4	38.6	-11.8	1.09
LBAM-X	-51.8	44.2	-7.6	1.25

Impact of EU Carbon Price Increase on EU Welfare and Global Emissions

	(iv) Economic Costs	(v) Environmental Benefit	(vi) Welfare = (iv) + (v)	(vii) Global Abatement [%]
B. Capital Stock via Perpetual Inventory Method (PIM)				
No-BAM	-31.8	19.3	-12.5	0.75
CBAM-EU	-31.2	21.4	-9.7	0.83
CBAM-ID	-17.8	34.9	17.1	1.35
CBAM-EZ	-18.8	31.5	12.8	1.22
LBAM	-28.4	22.3	-6.1	0.86
LBAM-X	-29.0	26.5	-2.5	1.02

Impact of EU Carbon Price Increase on EU Welfare and Global Emissions

	(iv) Economic Costs	(v) Environmental Benefit	(vi) Welfare = (iv) + (v)	(vii) Global Abatement [%]
C. Constant returns to scale and demand elasticity for all sectors				
No-BAM	-34.0	26.5	-7.5	0.64
CBAM-EU	-33.1	27.8	-5.3	0.67
CBAM-ID	-23.6	58.2	34.6	1.40
CBAM-EZ	-23.1	51.2	28.1	1.23
LBAM	-27.6	34.9	7.3	0.84
LBAM-X	-28.6	45.0	16.4	1.08

Backup Slides

Estimating Sectoral Demand Elasticities ε_s Calibration

- We follow Feenstra (1994), Broda & Weinstein (2006), and especially Soderbery (2015).
- Starting from the sectoral demand system, we express bilateral market shares δ_{ijst} as:

$$\log \delta_{ijst} = (1 - \varepsilon_s) \log P_{ijst} + (\varepsilon_s - 1) \log P_{ist}$$

- We take time differences to eliminate origin-sector fixed effects, and reference-country differences to remove importer-time effects:

$$\Delta^k \log \delta_{ijst} = (1 - \varepsilon_s) \Delta^k \log P_{ijst} + \epsilon^k_{ijst}$$

- Estimation uses EU import data (2005–2018) at the 4-digit ISIC level, converted from 8-digit NACE data.
- Import prices are constructed from unit values; market shares from bilateral import values.

Estimating Sectoral Demand Elasticities ε_s and Returns to Scale γ_s Calibration

- The supply equation links prices to market shares:

$$p_{ijst}^{1+\gamma_s} = \left(\mu_s \tau_{ijs} \tau_{Iijs} \tau_{Xijs} p_{Zj}^{\beta_s(\gamma_s+1)} \phi_{ijst}^{-(1+\gamma_s)}\right) (\delta_{ijst} \eta_{ist})^{\gamma_s}$$

- Taking logs and differencing twice (time and reference-country), the empirical supply equation becomes:

$$\Delta^k \log P_{ijst} = \frac{\gamma_s}{1+\gamma_s} \Delta^k \log \delta_{ijst} + \omega_{ijst}^k$$

- Identification relies on the orthogonality of demand and supply shocks: $\mathbb{E}(\epsilon_{ijst}^k \omega_{ijst}^k) = 0$.
- We estimate γ_s using the hybrid limited information maximum likelihood estimator from Soderbery (2015).
- The median estimated γ_s is 0.5, indicating decreasing returns to scale in most sectors.

Estimation of Output Elasticities α_s and β_s Calibration

- We estimate Cobb-Douglas production functions at the 4-digit NACE level using restricted-access German microdata from the AFiD census (*Amtliche Firmendaten in Deutschland*).
- AFiD covers ~50,000 German manufacturing plants annually (1998–2018) with detailed data on:
  - Employment, capital (constructed per Wagner (2010)),
  - Materials, energy use (electricity + fuels), and gross output.
- Germany serves as a proxy due to the lack of EU-wide plant-level energy use data (Wagner et al., 2020).

Estimation of Output Elasticities α_s and β_s Calibration

- Production functions are estimated using the proxy-variable GMM estimator by Wooldridge (2009).
  - Uses lags and either materials or energy as proxies.
  - Builds on Olley & Pakes (1996), Levinsohn & Petrin (2003); robust to critiques by Ackerberg et al. (2015).
- For each sector:
  - β_s: Output elasticity of energy.
  - α_s: Aggregated elasticity of capital, labor, and materials.
- Elasticities are converted to ISIC Rev. 4 using a NACE–ISIC concordance.
- Only elasticities with non-negative coefficients are retained; outliers are removed.
- Estimates are rescaled to match returns to scale implied by trade data.

Summary Statistics of Production Function Parameters and Demand Elasticities

	N	Mean	Median	Min	Max	SD
	(1)	(2)	(3)	(4)	(5)	(6)
α_s	131	0.541	0.530	0.061	0.993	0.306
β_s	131	0.086	0.063	0.001	0.393	0.085
γ_s	131	2.020	0.563	0.000	10.045	3.171
ε_s	131	4.613	2.415	1.317	18.078	5.124

Notes: Column 1 reports the number of observations for each parameter. Columns 2 and 3 show the mean and standard deviation for each parameter across all observations. Columns 4 to 6 present the median, minimum, and maximum values for each parameter.

Summary Statistics Fuel Shares

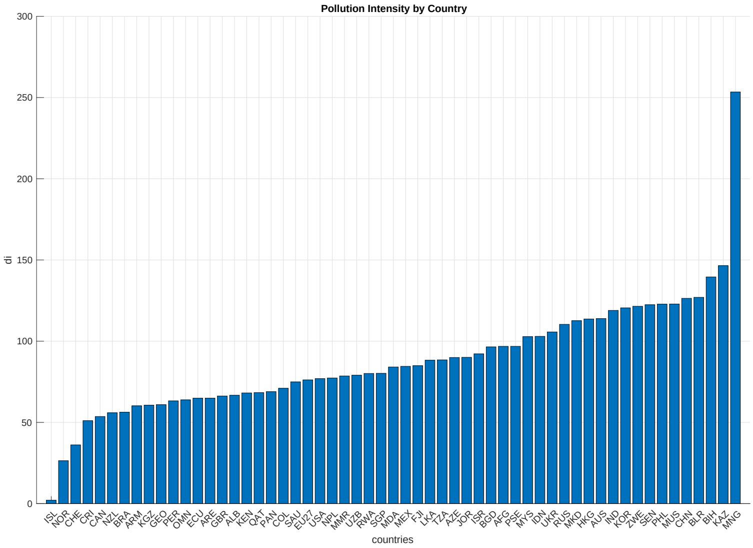
Variable	N	Mean	Median	Min	Max	SD	% imputed
Fuel share coal	74	0.175	0.114	0.000	0.605	0.164	21.6
Fuel share electricity	74	0.327	0.327	0.048	0.970	0.147	8.1
Fuel share natural gas	74	0.275	0.234	0.005	0.804	0.213	25.7
Fuel share oil	74	0.223	0.165	0.018	0.766	0.178	8.11

The table presents summary statistics of imputed and non-imputed fuel shares. Electricity followed by natural gas are the most used fuel types in our sample. The share of imputed observations ranges between 8 and 26%.

Summary Statistics Fuel Prices

Variable	N	Mean	Median	Min	Max	SD	% imputed
Price coal	74	146.564	127.837	8.736	480.300	97.224	71.6
Price electricity	74	133.405	107.044	0.777	518.742	101.327	5.5
Price oil	74	569.616	549.311	134.010	1026.786	155.381	48.6
Price natural gas	74	21.646	11.556	0.210	140.970	26.774	47.3

Carbon Intensities back



References

Ackerberg, D. A., Caves, K., & Frazer, G. (2015). Identification properties of recent production function estimators. *Econometrica*, 83(6), 2411–2451.

Broda, C. & Weinstein, D. E. (2006). Globalization and the Gains From Variety. *Quarterly Journal of Economics*, 121(2), 541–585.

Farrokhi, F. & Lashkaripour, A. (2025). Can trade policy mitigate climate change? *Econometrica*, forthcoming.

Feenstra, R. C. (1994). New product varieties and the measurement of international prices. *American Economic Review*, (pp. 157–177).

Levinsohn, J. & Petrin, A. (2003). Estimating Production Functions Using Inputs to Control for Unobservables. *Review of Economic Studies*, 70(2), 317–341.

Olley, S. & Pakes, A. (1996). The dynamics of productivity in the telecommunications equipment industry. *Econometrica*, 64(6), 1263–1298.

Rennert, K., Errickson, F., Prest, B., & *et al.* (2022). Comprehensive evidence implies a higher social cost of CO_2. *Nature*, 610, 687–692.

Soderbery, A. (2015). Estimating import supply and demand elasticities: Analysis and implications. *Journal of International Economics*, 96(1), 1–17.

Wagner, J. (2010). Estimated capital stock values for German manufacturing enterprises covered by the cost structure surveys. *Journal of Contextual Economics – Schmöllers Jahrbuch*, 130(3), 403–408.

Wagner, U. J., Kassem, D., Gerster, A., Jaraite, J., Klemetsen, M. E., Laukkanen, M., Leisner, J., Martin, R., Muûls, M., Munch, J. R., de Preux, L., Rosendahl, K. E., Schusser, S., & Nielsen, A. E. (2020). Carbon footprints of European manufacturing jobs: Stylized facts and implications for climate policy. CRC TR 224 Discussion Paper No. 250.

Wooldridge, J. M. (2009). On estimating firm-level production functions using proxy variables to control for unobservables. *Economics Letters*, 104(3), 112–114.