The Global Effects of Carbon Border Adjustment Mechanisms

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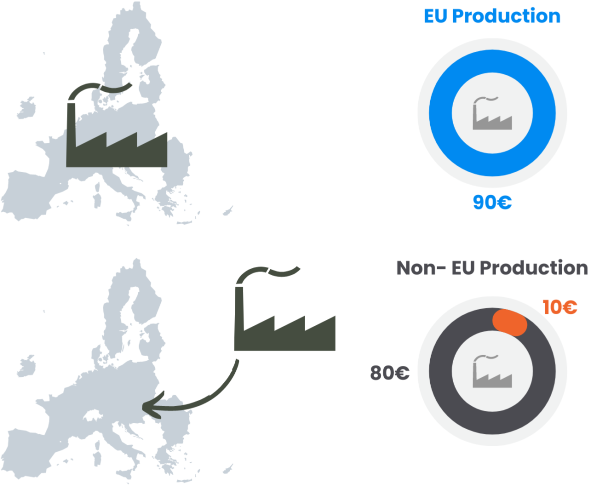
Carbon border adjustment mechanism (CBAM)



EU production is subject to the **EU-ETS***
(Assuming an ETS allowance price of 90€ per tonne of CO2)

Non-EU production is subject to a lower **ETS** and **CBAM certificates**

Climate change is a collective action problem

- Individual countries bear the costs of carbon regulation
    - While the benefits are shared globally
- CBAMs aim to realign incentives
    - Improving domestic competitiveness
    - Reducing emissions leakage
    - Encouraging carbon taxation abroad
- But CBAMs may disadvantage lower-income trading partners

This paper

- Quantitative analysis of European CBAM policies
  - Global equilibrium framework + microdata on key sectors
- CBAM impacts for a $100 European carbon tax
  - Competitiveness: domestic profits $\uparrow$ by $1B
  - Leakage: foreign emissions $\downarrow$ by 17.1 Mt
  - Incentives: Chinese costs $\downarrow$ by $1.5B
  - Incidence: similar for lower-income trading partners
- CBAM facilitates a Europe-China coalition
  - Marginal abatement costs $\downarrow$ by $30 per ton

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Literature

- International climate action and incomplete regulation
  Markusen 1975, Copeland & Taylor 1994, 1995, 2023, Hoel 1996, Rauscher 1997, Elliott et al. 2010, Nordhaus 2015, Böhringer et al. 2016, Kortum & Weisbach 2017, Clausing & Wolfram 2023, Harstad 2023, 2024, Brunel & Levinson 2025, Farrokhi & Lashkaripour 2025, Hsiao 2025

- Environmental effects of trade policy
  (Global equilibrium modeling) Böhringer et al. 2012, Larch & Wanner 2017, Shapiro & Walker 2018, Kortum & Weisbach 2023, Abuin 2024, Caliendo et al. 2024, Coster et al. 2024, Casey et al. 2025, Farrokhi et al. 2025, Garcia-Lembergman et al. 2025
  (Microdata + heterogeneity) Fowlie 2009, Fowlie et al. 2016, Fowlie & Reguant 2022, Chen et al. 2025

Policy timeline

- **EU CBAM** proposed in 2021
  - Phase-in starting October 1, 2023 with reporting only
  - Full implementation from January 1, 2026 for target sectors
- Elsewhere in Europe
  - UK and Norway targeting 2027 implementation
  - EFTA subject to EU ETS and thus exempt
- Expansion of **Chinese TPS** to target sectors
- Discussions in Australia, Brazil, Canada, Taiwan, and elsewhere

Initial target sectors

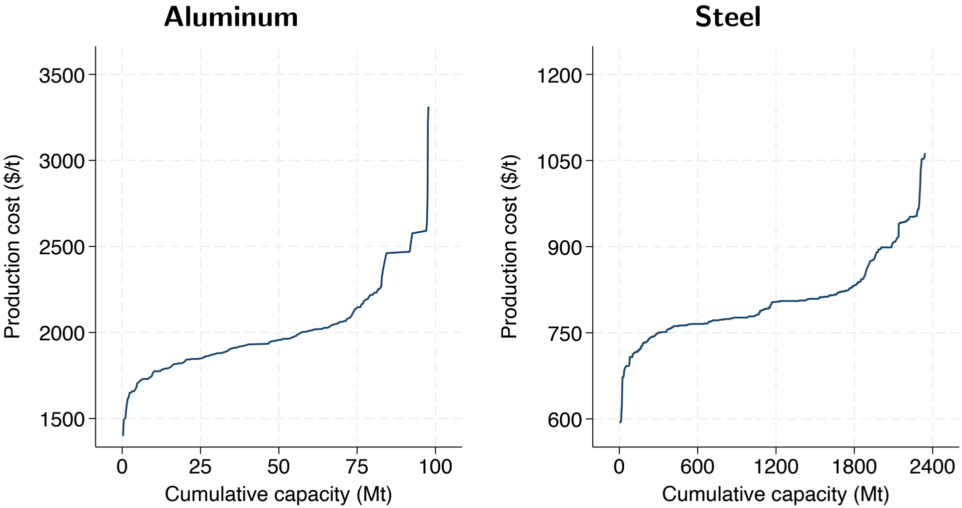
(%)	Trade Intensity	Global Emissions
Aluminum	41	3
Steel	23	11
Fertilizers	60	1
Electricity	2	33
Cement	2	6
Hydrogen	0.1	2

Data

Global data by plant for 2023

- Aluminum smelters from WoodMac (153 worldwide)
  - Public data and site visits
- Steel mills from Climate TRACE (892 worldwide)
  - Satellite and mill-level sensor data
- Production, capacity, costs, and emissions
  - Subnational carbon taxes and allowances

Production costs and capacity



Production quantities

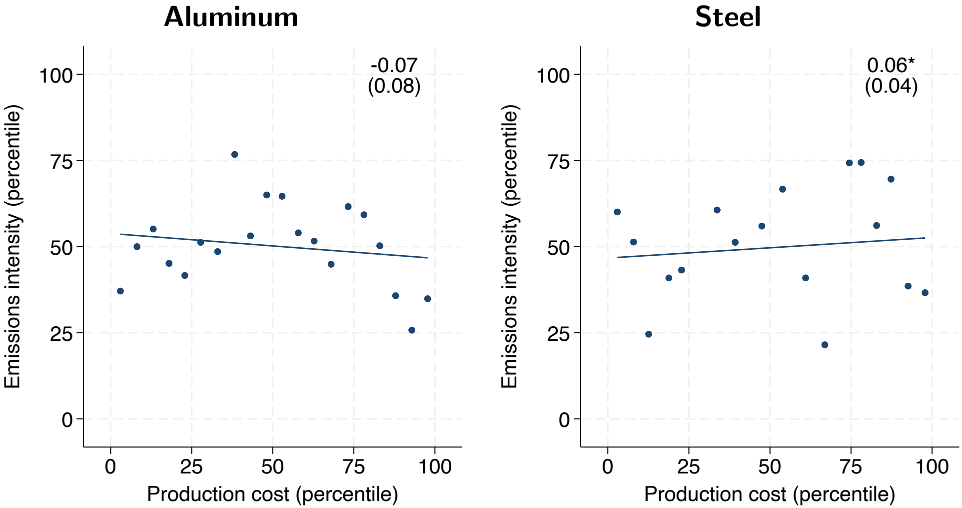
Aluminum

	Mt	%
China	49	58
India	5	6
Europe	5	5
USA	4	5
Russia	4	5
Rest of world	18	21

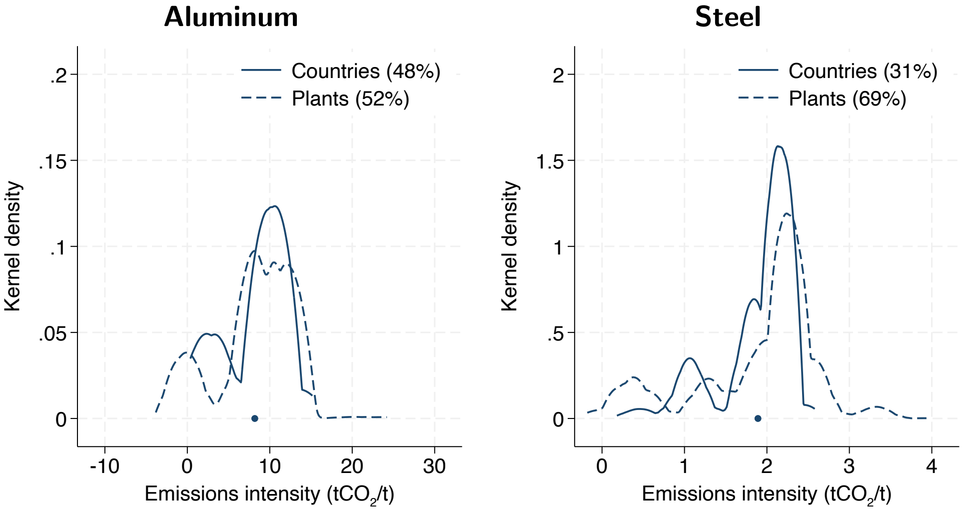
Steel

	Mt	%
China	860	51
Europe	153	9
Japan	88	5
USA	86	5
India	76	5
Rest of world	409	24

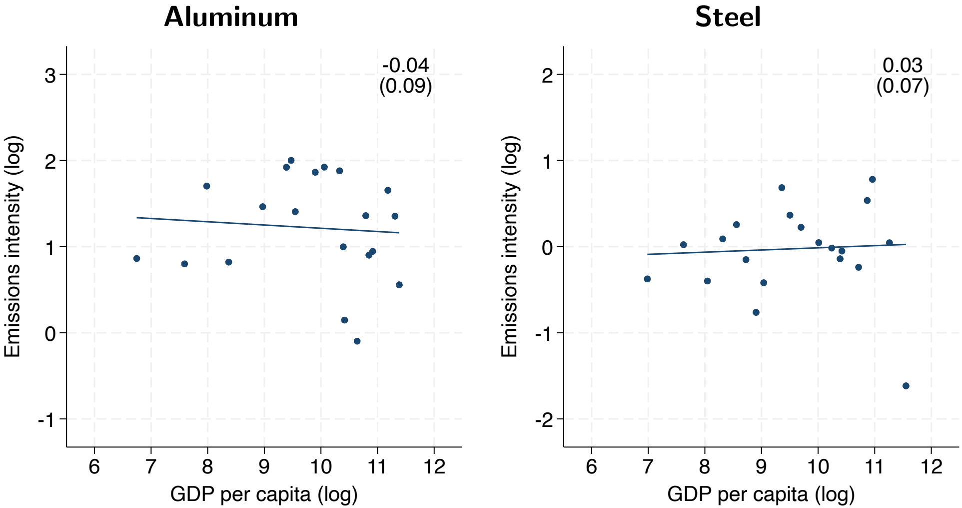
Carbon pricing shifts the competitive landscape



Heterogeneity both within and across countries



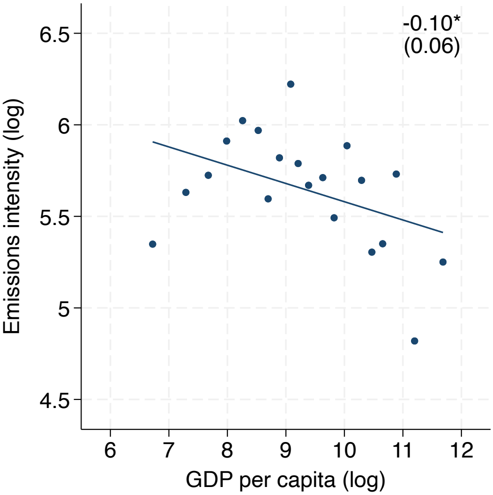
Flat emissions intensity by income



Even controlling for differences in production

	Aluminum		Steel	
	GDP	Controls	GDP	Controls
GDP per capita (log)	-0.0378	0.0148	0.0252	-0.0921
	(0.0896)	(0.111)	(0.0728)	(0.0597)
Primary production (%)		0.990**		1.461***
		(0.440)		(0.279)
Average production (Mt)		0.585*		0.202*
		(0.309)		(0.111)
State ownership (%)		-0.271		0.474**
		(0.291)		(0.201)
Foreign ownership (%)		-0.105		-0.541*
		(0.367)		(0.297)
Average plant age (years)		-0.00933		-0.00259
		(0.00662)		(0.00249)
Observations	38	34	77	77

Electricity emissions intensities explain aluminum



- Ang and Su 2016
- EEA 2025
- Electricity Maps 2025
- Ember 2025

Compressed emissions intensities explain steel

Top producers

	t
Kazakhstan	15.2
South Africa	14.2
India	13.5
Australia	12.7
China	10.2
UAE	6.6
Bahrain	6.6
Qatar	6.6
Saudi Arabia	6.5
Oman	6.4
World average	8.2

Top consumers

	t
Kazakhstan	2.6
Ukraine	2.4
South Africa	2.3
China	2.2
Serbia	2.2
Vietnam	2.1
India	2.0
Australia	1.9
Brazil	1.9
Japan	1.9
World average	1.9

Model

Environmental regulation with global trade

$p_i^R = P - \tau e_i$	carbon tax in **regulated** market R
$p_i^U = P$	no tax in **unregulated** market U
$D(P^*) = S(P^*)$	world market clears at price P (no CBAM)

- Competitiveness: R firms pay τ, but U firms do not
- Leakage: τ raises P, and U firms respond
- Incentives: U government free rides on lower e

- Incidence: depends on firm **data**

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CBAM pushes sales to U, such that $P^R > P^U$

$$p_i^R = \max\{P^R, P^U\} - \tau e_i \qquad R \text{ firms choose destination market}$$
$$p_i^U = \max\{P^R - \tau e_i, P^U\} \qquad U \text{ firms choose subject to } \textbf{CBAM}$$

$$D^R(P^{R*}) = S^R(P^{R*}, P^{U*}) \qquad \text{markets clear at prices } (P^R, P^U)$$
$$D^U(P^{U*}) = S^U(P^{R*}, P^{U*})$$

- Competitiveness: τ raises P^R more, helping R firms
- Leakage: τ raises P^U less, hurting U firms
- Incentives: U government can raise τ^U with same p_i^U

- Incidence: depends on firm **data**

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Demand $D^m(P^m)$ by market m

$$\log D^m = \delta^m + \varepsilon^m \log P^m$$

- Estimated with historical global data for metals j, years t
  - Assuming common elasticity and world prices
- Endogeneity: positive demand shocks raise prices in equilibrium
  - Instrument: Australia's share of global ore production

Demand $D^m(P^m)$ by market m

$$\boxed{\log D_{jt} = \delta_j + \delta_t + \varepsilon \log P_{jt} + \epsilon_{jt}}$$

- Estimated with historical global data for metals j, years t
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Demand elasticities

	Estimate	SE	Obs
1976 to 2024			
OLS	-0.730***	0.080	98
IV: Australian share of ore production	-0.930***	0.098	98
1998 to 2022			
OLS	-0.462***	0.053	50
IV: Australian share of ore production (AU)	-0.733***	0.134	50
IV: concentration of ore production (HHI)	-0.743***	0.152	50
IV: both AU and HHI	-0.728***	0.132	50

Supply $s_i^m(p_i^m)$ by plant i

$$
\begin{aligned}
u_{il}^m &= \overbrace{\beta(p_i^m - c_i) + \epsilon_i}^{v_i^m} + \epsilon_{il} && \text{choice to operate lines } l \\
o_i^m &= \exp(v_i^m)/[1 + \exp(v_i^m)] && \text{capacity utilization} \\
s_i^m &= \bar{s}_i o_i^m && \text{production}
\end{aligned}
$$

- Price p_i^m, cost c_i, logit shocks ϵ_{il}, capacity $\bar{s}_i$

- Constant marginal costs: heterogeneity across plants, not across lines (CRS)
- No market power: unconcentrated with many plants and firms
- No dynamic response: new construction is expensive and slow

Logit estimation with plants i, metals j, countries k

$$\log\left(\frac{o_i^m}{1-o_i^m}\right) = \beta(p_i^m - c_i) + \epsilon_i.$$

- Costs c_{ijk} are data, assuming $MC = AC$
  - Only need to estimate β, rather than full cost structure
- Endogeneity: aggregate supply shocks raise prices in equilibrium
  - Fixed effects: compare plants within markets, eliminating common prices
- Endogeneity: costs are correlated with unobserved technology
  - Fixed effects: compare plants that are observably similar

Logit estimation with plants i, metals j, countries k

$$\boxed{\log\left(\frac{o_{ijk}}{1-o_{ijk}}\right) = -\beta(\bar{\tau}_{jk}\bar{e}_{ijk} + c_{ijk}) + \mu_{jk} + \epsilon_{ijk}}$$

- Costs c_{ijk} are data, assuming $MC = AC$
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- Endogeneity: aggregate supply shocks raise prices in equilibrium
  - Fixed effects: compare plants within markets, eliminating common prices
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Supply elasticities

	Estimate	SE	Obs
OLS	-0.358***	0.076	1,055
FE: country-metal	0.241	0.224	1,005
FE: country-metal + controls	0.583**	0.231	987
FE: country-metal-group	0.602**	0.238	833

Observables: primary production, state ownership, foreign ownership, plant age

Counterfactuals

Policy simulations

- **European carbon tax** at \$100 per ton of CO_2
  - With vs. without a **CBAM** in place
  - Isolates the marginal impact of the CBAM
- Evaluate welfare relative to zero regulation
  - Europe (R), China (U/R), and rest of world (U)

Equilibrium price effects

Europe: $\tau^R = 100$

ΔP (%)	Europe	China	Rest of world
Without CBAM	0.41	0.41	0.41
With CBAM	1.22	0.33	0.33

- Without CBAM, regulation effect alone ($P \uparrow$)
- With CBAM, regulation + reallocation effects ($P^R > P^U$)
- Modest magnitudes because Europe is small

CBAMs boost competitiveness

Europe at $\tau^R = 100$

ΔPS (1B USD)	Europe	China	Rest of world
Without CBAM	-23.07	4.02	3.04
With CBAM	-22.07	3.17	2.61

- Without CBAM, R firms lose and U firms gain
- With CBAM, R loses $1B less at cost to U

CBAMs curb leakage

Europe at $\tau^R = 100$

ΔE (Mt CO_2)	Europe	China	Rest of world	Global
Without CBAM	-24.81	4.85	2.84	-17.12
With CBAM	-24.03	3.34	2.23	-18.45

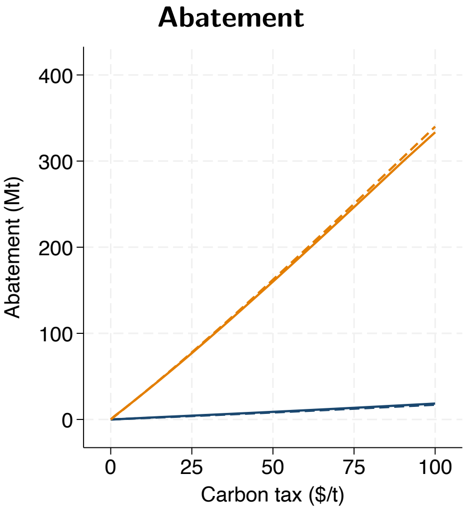
- Without CBAM, R emissions fall and U emissions rise
- With CBAM, global emissions fall by 1.33 Mt more

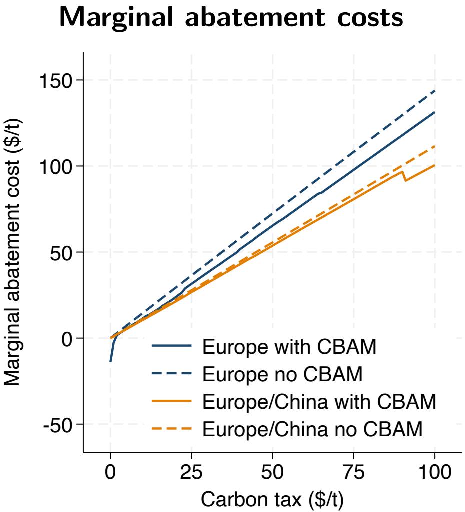
CBAMs encourage Chinese regulation

Europe at $\tau^R = 100$; China joining at $\tau^R = 100$

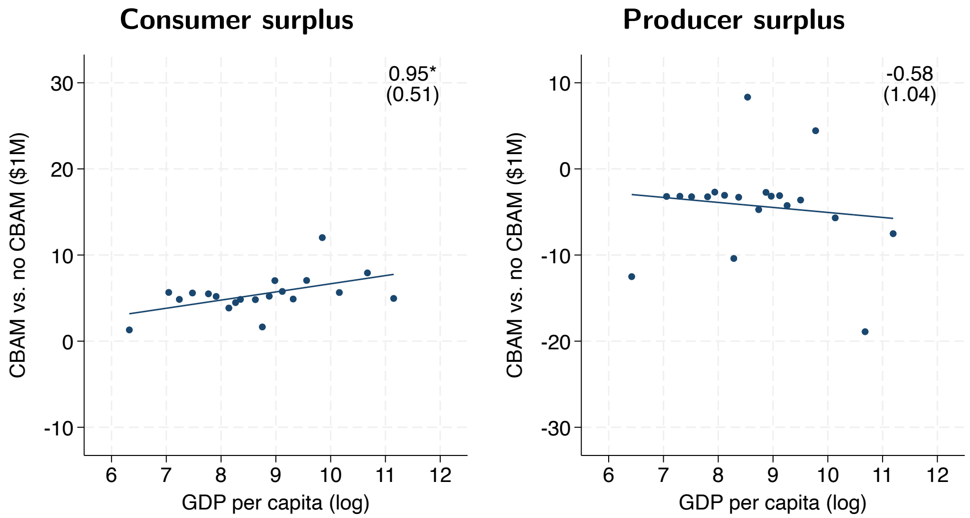
Europe:	With CBAM		No CBAM
China:	With CBAM	No CBAM	No CBAM
Chinese welfare ($1B)	-18.22	-20.05	-19.69
Global emissions (Mt)	-314.9	-321.6	-322.9
Average cost ($/t)	57.86	62.34	60.98

Global abatement





European CBAM impacts by income



European CBAM impacts by country

Consumer surplus

Largest gains ($1M)		Largest losses ($1M)	
China	841	Germany	-340
USA	114	Italy	-221
India	79	France	-116
Japan	52	Spain	-109
South Korea	36	Poland	-88

Producer surplus

Largest gains ($1M)		Largest losses ($1M)	
Germany	203	China	-847
Italy	167	India	-79
Norway	156	Russia	-66
France	87	Japan	-42
Iceland	77	Canada	-39

Other counterfactuals

- Implementing firm- vs. country-level regulation
- Green technology and expansion
- Phasing out EU allowances
- Partial border adjustment

Conclusion

Summary

- Quantitative equilibrium analysis of European **CBAM policies**
  - Boosts competitiveness, curbs leakage, and encourages regulation
  - Without disproportionate impacts on lower-income countries
- Domestic advantages may help
  - To establish carbon regulation in the first place
  - To sustain international coordination