Trade Policy and the Environment

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Overview

- Parent literatures
  - Trade and the environment
  - Trade policy
- Trade policy for climate mitigation
- Trade policy for climate adaptation

Trade and the environment

- Copeland, Shapiro, and Taylor 2022 (Handbook of International Economics)

- Does trade cause deforestation and endangered species depletion?
- How does globalization affect air and water pollution?
- Do trade and investment create a race to the bottom in environmental policy?
- How important are environmental impacts of transporting goods?

Trade policy

- Caliendo and Parro 2022 (Handbook of International Economics)

- Classic terms-of-trade effects that shape trade policy
- Shift-share methods for empirical analysis of trade policy
- Quantitative modeling of aggregate and distributional effects in equilibrium

Trade policy for climate mitigation

1. International environmental policy coordination
   - Nordhaus 2015, Böhringer et al. 2016, Kortum and Weisbach 2022, Bourany 2024, Farrokhi and Lashkaripour 2024, **Hsiao 2025**
2. Environmental effects of trade policy
   - Copeland and Taylor 2003, Kortum and Weisbach 2017, Shapiro 2021, Xiang 2023, Abuin 2024, Harstad 2024, Casey et al. 2025
3. Carbon border adjustment mechanisms
   - Markusen 1975, Copeland and Taylor 1994, 1995, Hoel 1996, Rauscher 1997, Fowlie 2009, Elliott et al. 2010, Fowlie et al. 2016, Kortum and Weisbach 2017, 2022, Coster et al. 2024, **Clausing et al. 2025**

Trade policy for climate adaptation

1. Global adaptation via trade
   - Costinot et al. 2016
2. How trade interacts with other mechanisms
   - Crop switching (Baldos et al. 2019, Hultgren et al. 2022)
   - Land and water use (Carleton et al. 2022)
   - Sectoral reallocation (Rudik et al. 2022, Nath 2023)
   - Migration (Cruz and Rossi-Hansberg 2023, Conte 2024)
   - Technology (Farrokhi and Pellegrina 2023)
   - Government policy (**Hsiao et al. 2025**)

Three papers

1. **Deforestation** and agricultural land use
   - Climate mitigation (Hsiao 2025)
2. **Food policy** and extreme heat shocks
   - Climate adaptation (Hsiao, Moscona, and Sastry 2025)
3. **EU CBAM** and its distributional impacts
   - Climate mitigation (Clausing, Colmer, Hsiao, and Wolfram 2025)

Deforestation

Coordination and Commitment in International Climate Action

- How effective are import tariffs as a substitute for domestic regulation?
  - Target world prices (via demand) instead of production directly
- **Leakage** and **commitment** issues
  - From incomplete regulation and sunk emissions
- **Dynamic empirical framework** for green trade policy
  - Estimated with satellite data and Euler methods

Dynamic elements

- **Theory**
- Data
- **Estimation**
- Counterfactuals

Palm oil

- IO tradition: frozen pizza, detergent, gasoline, and other homogeneous goods
- Produced largely in Indonesia and Malaysia (85%)
  - Drives widespread deforestation
  - And destruction of carbon-rich peatlands

MARGARINE

CHOCOLATE

SOAP

BIODIESEL

COOKIES

PIZZA DOUGH

SHAMPOO

DETERGENT

PACKAGED BREAD

ICE CREAM

INSTANT NOODLES

LIPSTICK

BIODIESEL

PIZZA DOUGH

DETERGENT

Almost ideal demand system (Deaton & Muellbauer 1980)

- Demand specified in expenditure shares
  1. ω_{okt}: palm vs. other oils (soybean, rapeseed, sunflower, coconut, and olive)
  2. $\ln P_{kt}$: translog price index

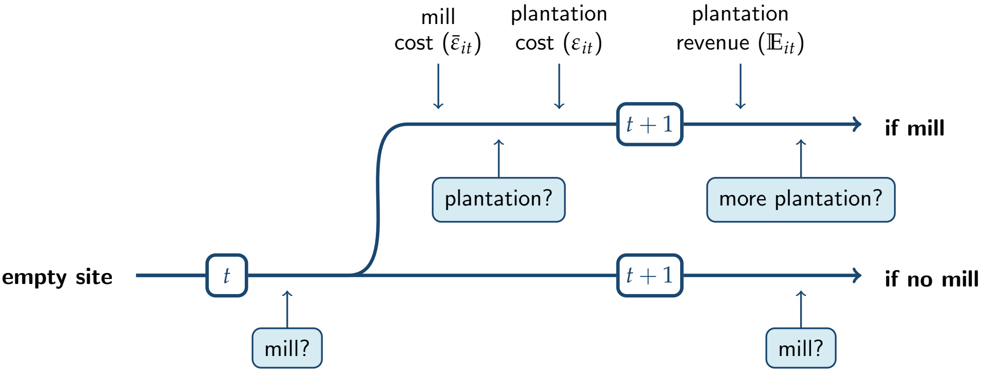
- **Estimation:** iterated linear least squares (Blundell & Robin 1999)

Dynamic supply with sunk investment

- **Sites:** units of land that invest in palm oil (potential entrants)
  - Active sites have one **mill** + some **plantations**

- Entry-investment game with dynamic competitive equilibrium
  - Invest/emit today (no exit) $\rightarrow$ revenues in every future period (net of tariffs)
  - (Expected) future prices matter, not just prices today

Timeline: discrete + continuous choices



Choice and state variables

- Observed choices
  - Mills m_{it}, plantations n_{it}
- Observed states
  - Endogenous mills M_{it}, plantations N_{it}
  - Exogenous world prices p_t, yields y_{it}, cost factors x_i, region g_i
- Unobserved states
  - Mill shocks $\bar{\varepsilon}_{it}$ (logit), plantation shocks ε_{it}

Spatial data

- **Investment:** plantations, mills over time via **satellite**

  PALSAR, MODIS, Landsat: Xu et al. (2020), Song et al. (2018); Universal Mill List: WRI, CIFOR

- **Revenues:** prices, quantities (yields)

  Prices: IMF, World Bank; PALMSIM: Hoffmann et al. (2014); Climate: WorldClim

- **Cost factors:** road, port, urban distances; carbon stocks

  Global Roads Inventory Project; World Port Index, World Port Source; Badan Pusat Statistik

Estimation

- **Euler methods:** classic continuous + newer discrete CCP (Hall 1978, Scott 2013)
  - Short-term perturbation: today vs. delay, so long term cancels
- **Assuming** long-lived owners, atomistic sites, rational expectations
  - Allows instruments, non-stationarity, serial correlation

Intensive-margin continuous choice (plantations)

- **Euler equation:** today vs. delay

$$\beta \mathbb{E}_{it}[r'_{it+1}(n_{it})] = c'_{it}(n_{it}) - \beta \mathbb{E}_{it}[c'_{it+1}(n_{it+1})]$$

- For linear revenues and convex costs (with convexity ψ),

$$n_{it} - \beta n_{it+1} = \frac{\alpha}{\psi} \beta r_{it+1} - \Delta c_{it} \left(\frac{\theta}{\psi} \right) + \eta_{it}$$

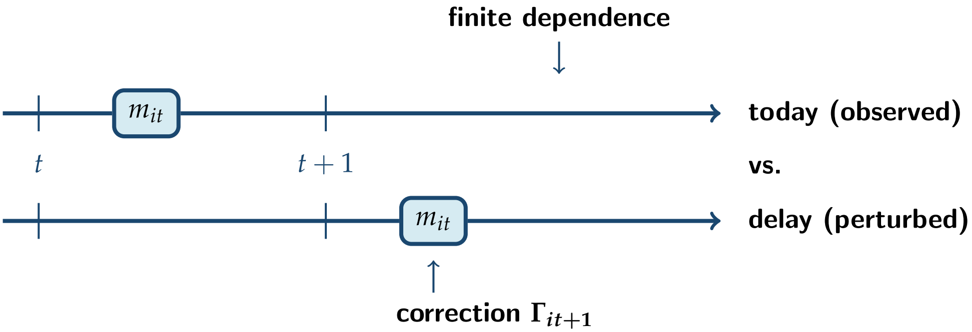
- **Intuition:** continuation values are embedded in agents' choices
    - Observed realizations proxy for unobserved expectations
    - With expectational error η_{it}, where $\mathbb{E}_{it}[\eta_{it} | \mathcal{J}_{it}] = 0$ under rational expectations

Regression equation

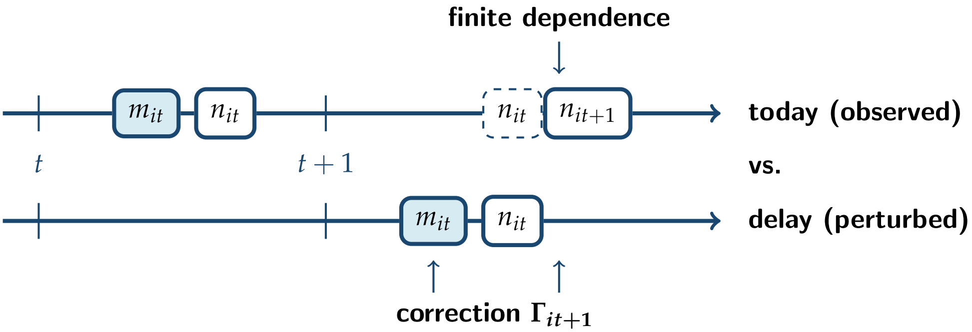
$$\underbrace{n_{it} - \beta n_{it+1}}_{\text{data}} = \frac{\alpha}{\psi}\beta r(\underbrace{p_{t+1}, y_{it+1}}_{\text{data}}) - \Delta c_{it}\left(\underbrace{x_i}_{\text{data}}, \overbrace{\varepsilon_{it}}^{\text{error}}; \frac{\theta}{\psi}\right) + \overbrace{\eta_{it}}^{\text{error}}$$

- **Identification:** market price variation + individual suitability
- **Endogeneity:** η_{it} correlated with (p_{t+1}, y_{it+1}), but not (p_t, y_{it}), so use IV

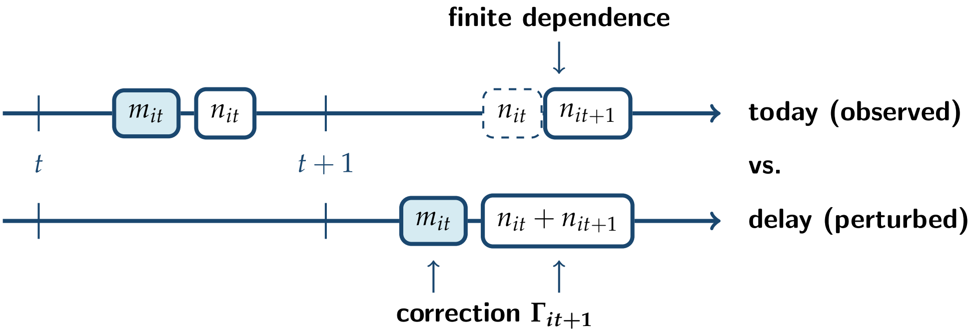
Extensive-margin discrete choice (mills)



Extensive-margin discrete choice (mills)



Extensive-margin discrete choice (mills)



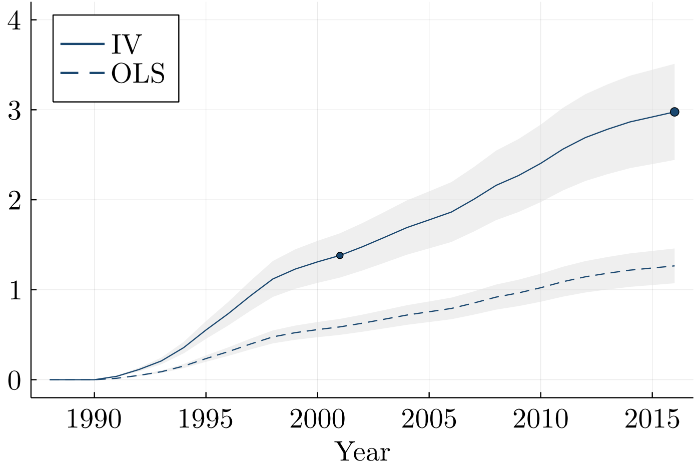
Regression equation

$$\underbrace{\ln\left(\frac{\pi_{it}}{1-\pi_{it}}\right) - \beta \ln \pi_{it+1} = \frac{1}{2}\psi n_{it}^2}_{\text{from data}} - \Delta\bar{c}_{it}(\underbrace{x_i}_{\text{data}};\bar{\theta}) + \overbrace{\bar{\eta}_{it}}^{\text{error}}$$

- **Identification:** same as intensive margin, as embodied by n_{it}
- **Endogeneity:** $\bar{\eta}_{it}$ uncorrelated with n_{it} by rational expectations

- **Challenge:** n_{it} only observed for intensive-margin sample
  - Use predicted n_{it} for extensive-margin sample, assuming $\bar{\varepsilon}_{it}$ and ε_{it} uncorrelated
  - Results robust to test for correlated shocks

Larger elasticities for long-run price changes



Counterfactuals

- Still need to solve the model
  - Common world prices each year
- Import tariffs with coordination and commitment
  - Coordination and commitment achieve most of first best
  - EU abatement costs of $15 per ton of CO_2, even with compensating transfers
- Policy simulations: unilateral EU tariffs, domestic export taxes, CBAMs

Food Policy

Food Policy in a Warming World

- Trade policy responds to extreme heat shocks
  - Example: March 2022 heat wave → Indian wheat export ban

- Redistributes welfare losses both within and across countries
  - Through equilibrium price effects of trade policy responses
  - And complicates adaptation through trade

- Static model for static story

This paper

1. **Empirics:** new global data by country, crop, year (1980-2011)
    - Domestic shocks lead to consumer aid, especially during elections
    - Foreign shocks lead to producer aid, possibly offsetting consumer aid
    - Persistent effects, including for longer-run changes
2. **Theory:** model of agricultural policy and trade
    - To rationalize observed policy responses
    - Government considers redistribution and revenues
3. **Quantification:** how policy responses affect incidence of climate damages
    - Policy responses shield domestic consumers by stabilizing prices

Data on shocks: extreme heat exposure

- Capture that extreme heat drives yield variability (Schlenker & Roberts 2009)
  - ERA-5 re-analysis data on temperatures
  - EarthStat data on geography of crop production (Monfreda et al. 2008)
  - ECOCROP data on crop-specific temperature sensitivity (Moscona & Sastry 2022)

- Exposure by country ℓ, crop k, year t, aggregating over cells c

$$\text{ExtremeHeat}_{\ell k t} = \sum_{c \in \ell} \frac{\text{Area}_{ck}}{\sum_{c' \in \ell} \text{Area}_{c'k}} \cdot \text{DegreeDays}_{ct}(T_k^{\text{max}})$$

Data on policy: nominal rate of assistance

- "Distortions to Agricultural Incentives" project (Anderson & Valenzuela 2008)
  - 80 products, 82 countries, 85% of global production (1955-2011)
  - Wedge between domestic and international prices
  - "Pro-consumer" if $NRA_{\ell kt} < 0$

- Captures multiple dimensions of policy
  - Quantity instruments, input-market interventions, temporary measures
  - But some subjectivity in measurement

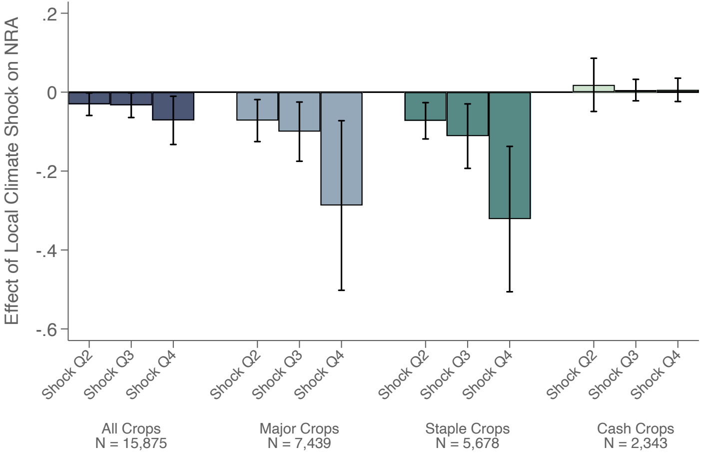
How does extreme heat affect trade policy?

$$\mathsf{NRA}_{\ell kt} = g(\mathsf{ExtremeHeat}_{\ell kt}) + \gamma_{\ell t} + \delta_{kt} + \mu_{\ell k} + \varepsilon_{\ell kt}$$

- Country ℓ, crop k, year t, quartile dummies $g(\cdot)$
- Fixed effects by country-year, crop-year, country-crop

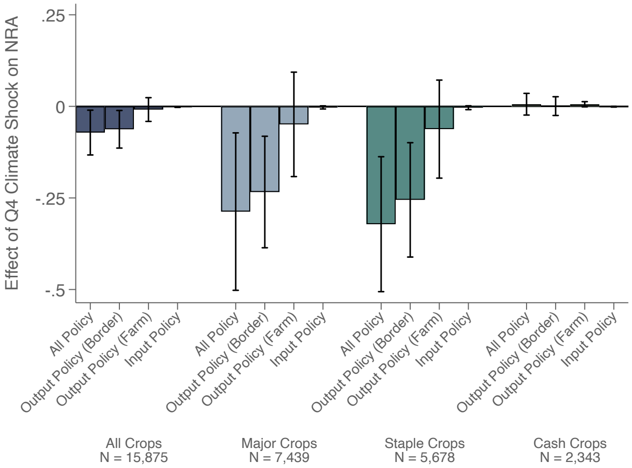
- **Identification:** some crops get worse shocks due to physiology, geography

Extreme heat induces pro-consumer policy



$$\text{NRA}_{\ell kt} = g(\text{ExtremeHeat}_{\ell kt}) + \gamma_{\ell t} + \delta_{kt} + \mu_{\ell k} + \varepsilon_{\ell kt}$$

Effects concentrated in border policies



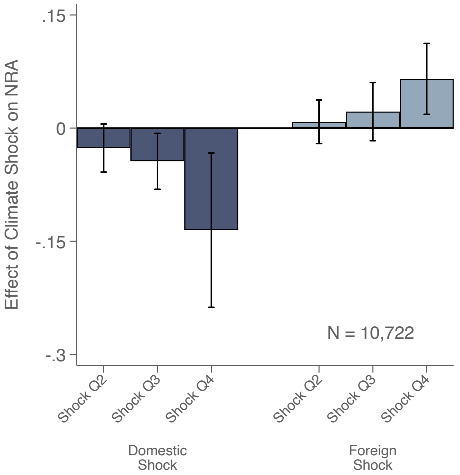
$$\mathrm{NRA}_{\ell kt}^{\text{type}} = g(\text{ExtremeHeat}_{\ell kt}) + \gamma_{\ell t} + \delta_{kt} + \mu_{\ell k} + \varepsilon_{\ell kt}$$

How do foreign shocks affect trade policy?

$$\text{NRA}_{\ell kt} = g(\text{ExtremeHeat}_{\ell kt}) + h(\text{ForeignExtremeHeat}_{\ell kt}) + \gamma_{\ell t} + \delta_{kt} + \mu_{\ell k} + \varepsilon_{\ell kt}$$

- Country ℓ, crop k, year t, quartile dummies $g(\cdot)$ and $h(\cdot)$
- Fixed effects by country-year, crop-year, country-crop
- ForeignExtremeHeat: trade partner shocks, weighted by pre-period trade shares

Foreign shocks induce pro-producer policy



$$\text{NRA}_{\ell kt} = g(\text{ExtremeHeat}_{\ell kt}) + h(\text{ForeignExtremeHeat}_{\ell kt}) + \gamma_{\ell t} + \delta_{kt} + \mu_{\ell k} + \varepsilon_{\ell kt}$$

Model of trade policy with shocks

- Prices: redistributive motives (Grossman & Helpman 1994; Bates 2014)
- Revenue: terms-of-trade manipulation (Johnson 1951)

- Market clearing $q = y + m$

$$\underbrace{q = p^{-\epsilon_d}}_{\text{Domestic demand}} \qquad \underbrace{y = \omega p^{\epsilon_s}}_{\text{Domestic supply}} \qquad \underbrace{x = \omega' p^{-\epsilon_x}}_{\text{Foreign net demand}}$$

- Tax wedge α between domestic price p^* and international price $\frac{p^*}{1+\alpha}$
- Government maximizes weighted sum of surplus

$$\max_{\alpha \in [-1,\infty)} \left\{ \lambda^C CS + \lambda^P PS + \lambda^G G \right\}$$

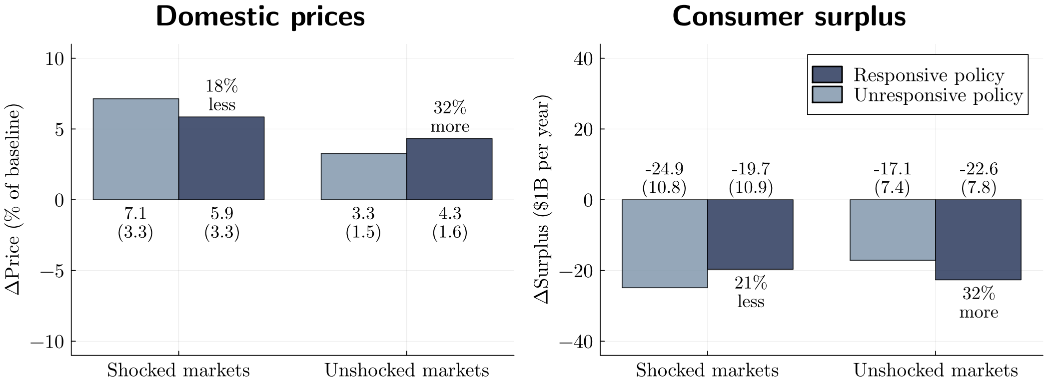
Quantitative model

- Many countries + estimated impacts of heat shocks on production and policy
  - Goals: equilibrium welfare impacts, characterize incidence, isolate policy effects

$$
\begin{aligned}
\text{demand} \qquad & \log q_{\ell k} = \log q^0_{\ell k} - \epsilon_d \log[(1+\alpha_{\ell k})p_k] \\
\text{supply} \qquad & \log y_{\ell k} = \log y^0_{\ell k} + \epsilon_s \log[(1+\alpha_{\ell k})p_k] - f(\text{ExtremeHeat}_{\ell k}) \\
\text{NRA} \qquad & \alpha_{\ell k} = \alpha^0_{\ell k} - g(\text{ExtremeHeat}_{\ell k}) + h(\text{ForeignExtremeHeat}_{\ell k})
\end{aligned}
$$

$$
\text{equilibrium} \qquad \sum_{\ell} q_{\ell k} = \sum_{\ell} y_{\ell k} \quad \forall k
$$

In shocked markets, policy responses stabilize prices



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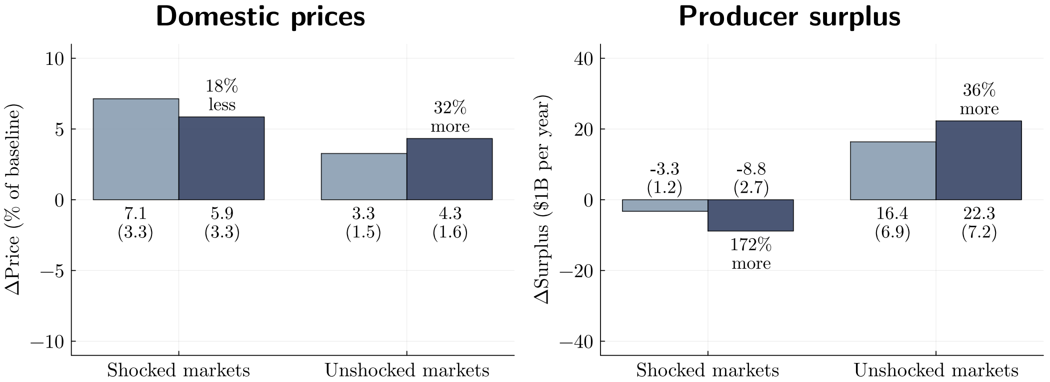

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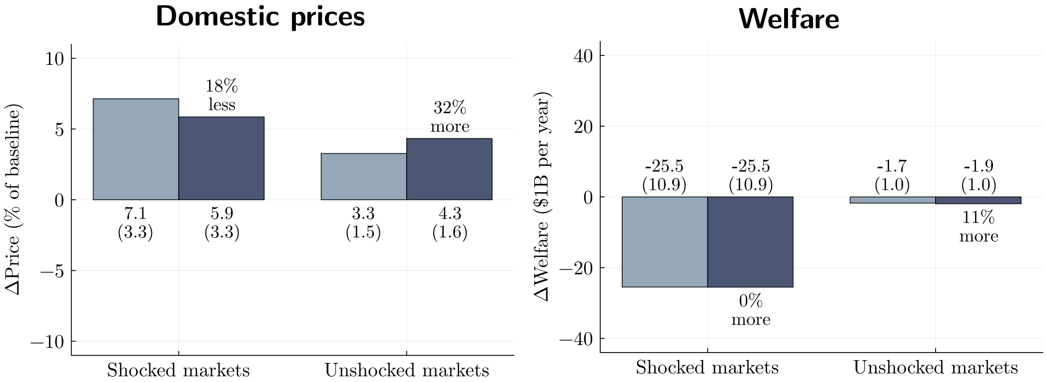
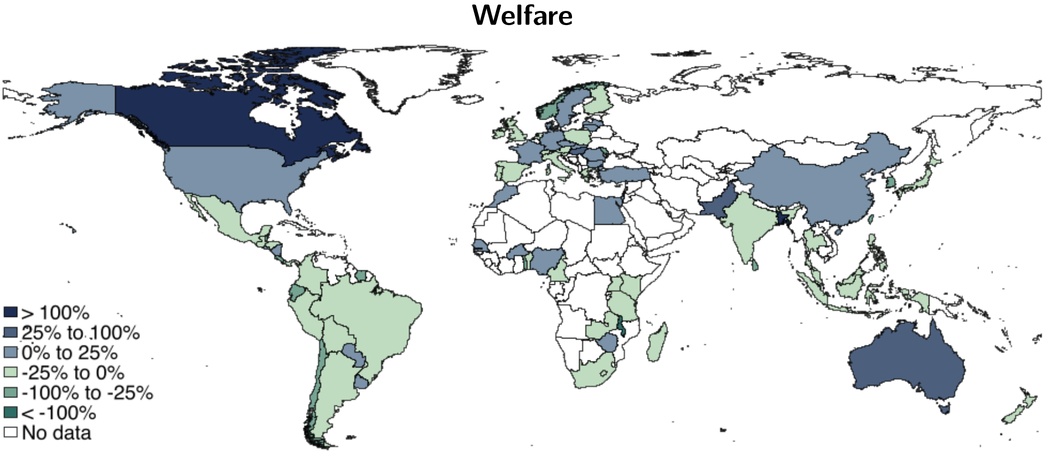


Across countries, policy responses affect pre-existing distortions



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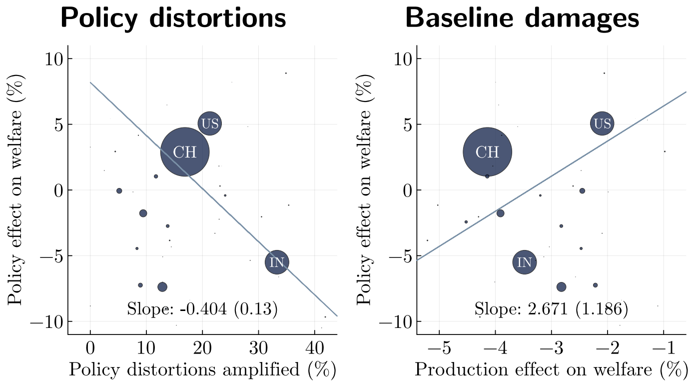
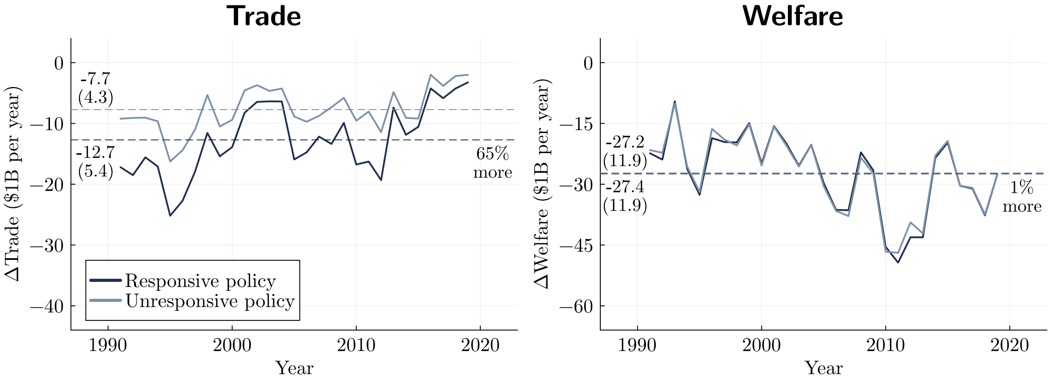
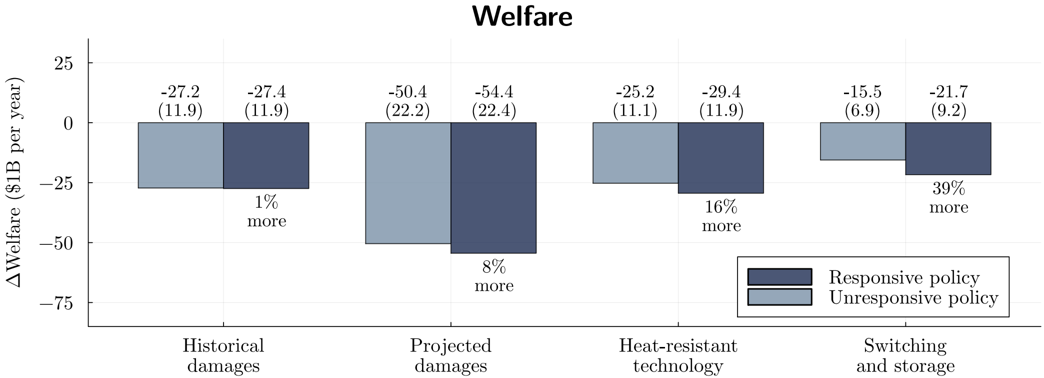


Over time, policy responses reduce trade

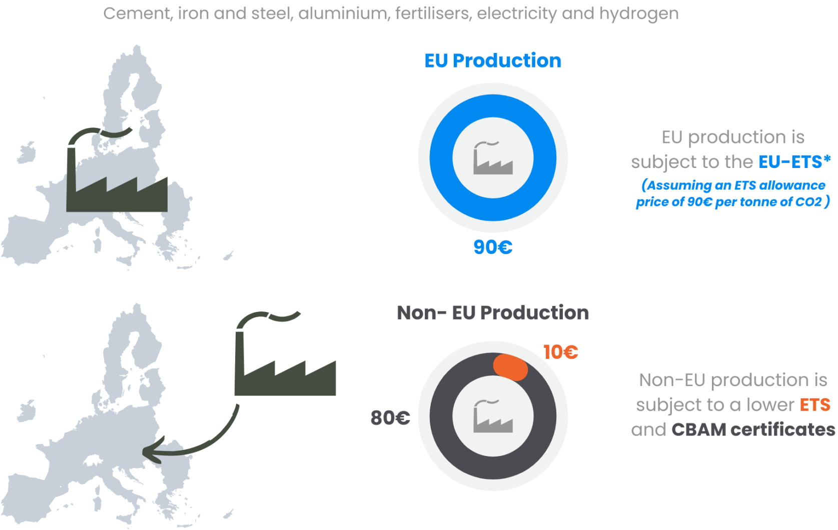


In projections, policy responses worsen climate damages



EU CBAM

The Global Effects of Carbon Border Adjustment Mechanisms



Three motivations and one concern

- Boost domestic competitiveness
- Curb foreign emissions leakage
- Encourage foreign regulation

- But may disadvantage lower-income trading partners
  - Guardian (2024): "India seeks UK carbon tax exemption in free trade deal talks"
  - Bloomberg (2024): "EU CBAM Damaging ASEAN Businesses?"

This paper

1. Detailed global data on aluminum and steel
   - Key sectors targeted in first phase of EU/UK CBAM
   - Most emissions-intensive and heavily traded
2. Descriptive analysis of emissions
   - Lower-income countries not more emissions-intensive
3. Quantitative equilibrium model of regulation and trade
   - Welfare impacts of carbon taxation and CBAM

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

- UK CBAM announced in 2023, targeting implementation by 2027

- In discussion in Canada, Australia, and Taiwan
- Expansion of Chinese ETS to cover target sectors

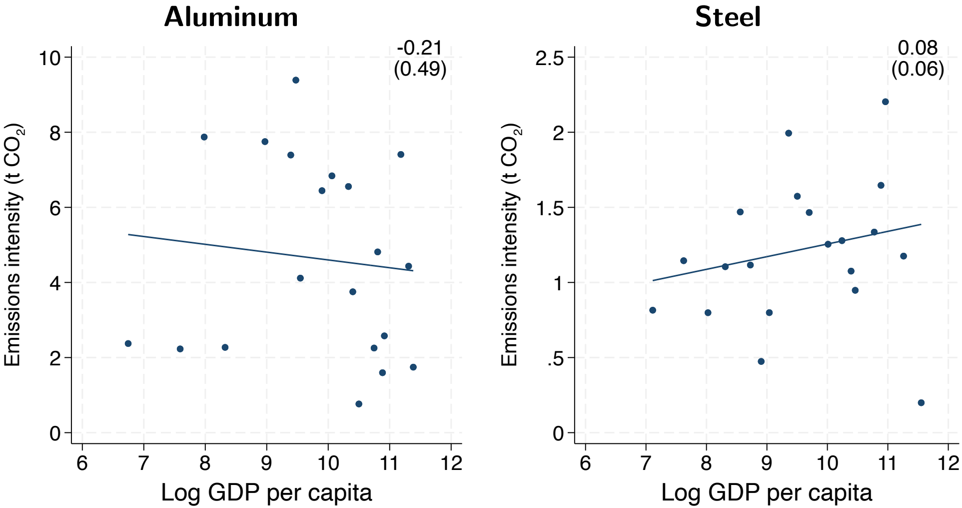
Initial target sectors

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

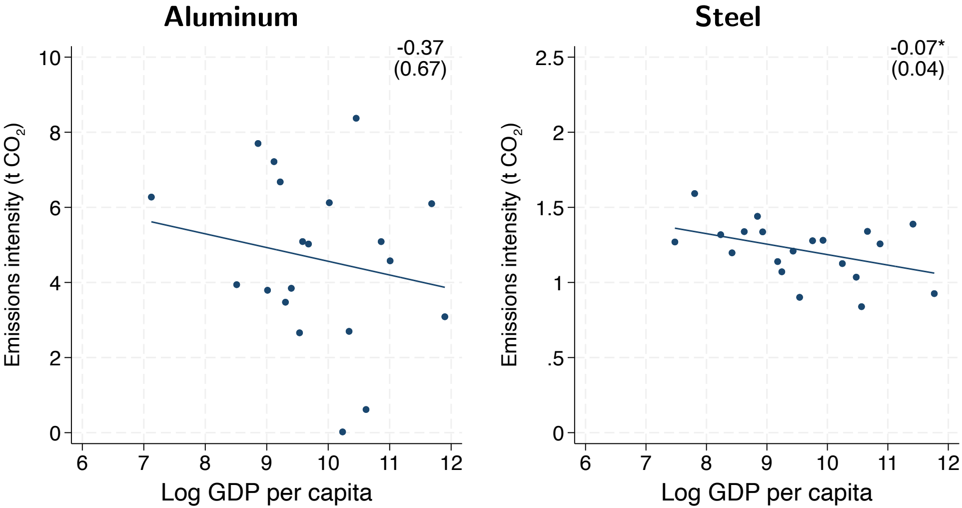
Global data by plant for 2023

- Aluminum smelters from WoodMac
  - 153 worldwide with some Chinese smelters aggregated
  - Public data and site visits
  - LIC producers: 7% of global production, 9% of global emissions
- Steel mills from Climate TRACE
  - 892 worldwide with capacity above 500k tons
  - Satellite and mill-level sensor data
  - LIC producers: 7% of global production, 6% of global emissions
- Production, capacity, costs, and emissions
  - Primary and secondary plants, Scope 1 and 2 emissions

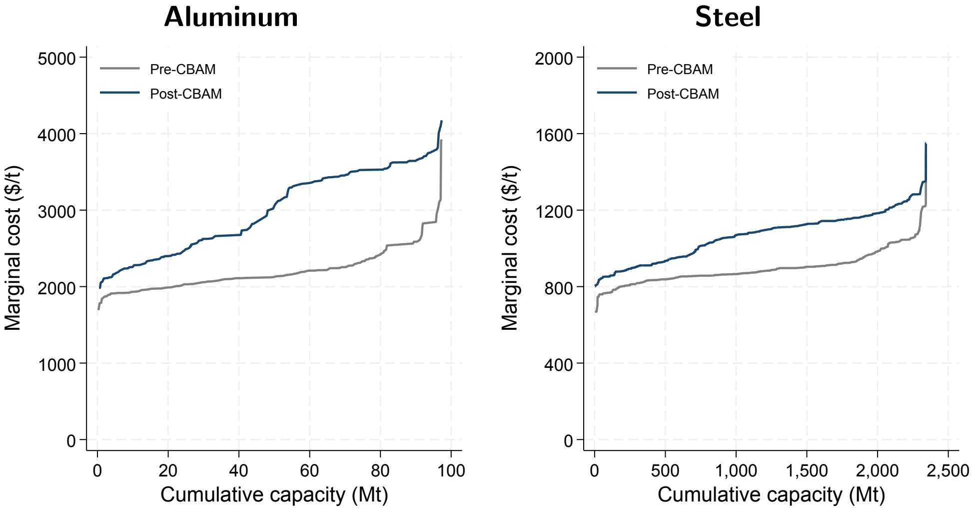
Emissions intensity by income



Controlling for compositional differences in production



CBAMs add to costs



Modeling environmental regulation with global trade

- Demand by market, supply by plant
  - Regulated and unregulated markets R and U
- Regulator in R considers a CBAM
  - Plants can shift sales across markets
  - Will quantify distributional effects

Demand by market m

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

- Log-linear with calibrated $\varepsilon^m = -0.25$ (Söderholm & Ekvall 2020)

Supply by plant i

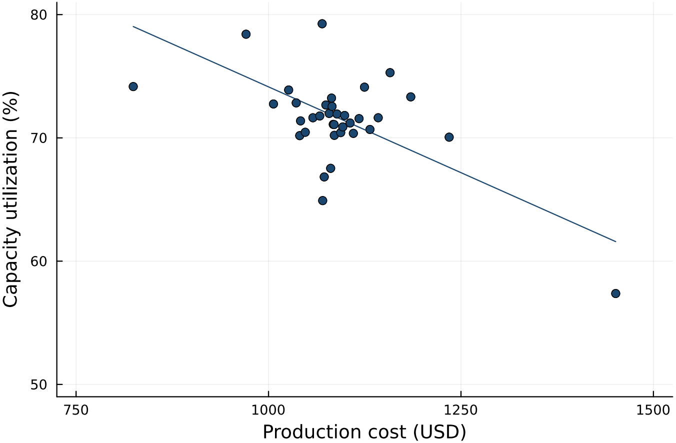
$$s_i^m = \bar{s}_i o_i^m, \quad o_i^m = \frac{\exp(v_i^m)}{1 + \exp(v_i^m)}$$

$$u_{il}^m = v_i^m + \epsilon_{il}, \quad v_i^m = \beta(p_i^m - c_i) + \epsilon_i$$

- Production s_i depends capacity utilization o_i^m via choice to operate lines ℓ
- Observed capacity $\bar{s}_i$, cost c_i, and price p_i^m

- Constant marginal costs, so only capture heterogeneity *across* plants
- No market power, but have many plants

Logit estimation with metals j, countries k



$$\log\left(\frac{o_{ijk}}{1-o_{ijk}}\right) = \beta(P_j - \bar{\tau}_k \bar{e}_{ijk} - c_{ijk}) + \mu_j + \mu_k + \epsilon_{ijk}$$

Carbon taxation

$$p_i^m = P^m - \tau^m e_i$$

$$\log e_i = \log \bar{e}_i - \gamma(\tau^m - \bar{\tau}^m)$$

- Without a CBAM, $P^m = P$ and $D(P^*) = S(P^*)$
- Regulation-induced abatement with calibrated $\gamma = 0.3$ (Sen & Vollebergh 2018)
  - Relative to emissions $\bar{e}_i$ and regulation $\bar{\tau}^m$ in the data

Carbon border adjustment mechanism

$$\alpha^R = \tau^R - \tau^U > 0$$

$$\begin{aligned} p_i^m &= \max\{p_i^{mR}, p_i^{mU}\} \qquad & p_i^{RR} &= P^R - \tau^R e_i \qquad & p_i^{UR} &= P^R - \tau^R e_i \\ r_i^m &= \mathbb{1}(p_i^{mR} > p_i^{mU}) \qquad & p_i^{RU} &= P^U - \tau^R e_i \qquad & p_i^{UU} &= P^U - \tau^U e_i \end{aligned}$$

- Plants choose destination market with best net price p_i^m
  - Given prices (P^R, P^U) and home regulation (τ^R, τ^U)
  - Pay home + border regulation (without export rebate)

Markets clear

$$D^R(P^{R*}) = S^R(P^{R*}, P^{U*}; \alpha^R)$$
$$D^U(P^{U*}) = S^U(P^{R*}, P^{U*}; \alpha^R)$$

- CBAM induces reallocation and price divergence
  - $P^R > P^U$: R expresses green preference and must pay for it

- Can compute welfare: CS, PS, G, E

Counterfactual policy simulations

- Carbon taxation in market R
  - Relative to zero regulation with $\tau^R = \tau^U = 0$
  - With and without a CBAM

- Evaluate global effects
  - R: EU + UK [+ China]
  - U: all other countries
  - UL: low and lower-middle income (World Bank)
  - UH: upper-middle and high income (World Bank)

EU/UK policy evaluation

EU/UK carbon taxation at \$100 per ton of CO_2

	No CBAM		With CBAM	
Impact	R	U	R	U
Price (%)	0.64	0.64	2.52	0.46
Emissions (Mt CO_2)	-93.2	13.6	-91.3	7.87
Welfare (1B USD)	-0.02	1.02	0.05	0.87
Consumer surplus (1B USD)	-1.22	-11.0	-4.40	-8.20
Producer surplus (1B USD)	-17.8	12.0	-15.5	9.07
Government revenue (1B USD)	19.0	0.00	19.9	0.00
Welfare with emissions reductions (1B USD)	7.94	1.02	8.39	0.87

Other results

1. Regulation and reallocation effects
2. CBAMs boost competitiveness
3. CBAMs curb leakage
4. CBAMs encourage regulation