Trade, Firm Delocation, and Optimal Climate Policy

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Background

Existing Climate Agreements Have Failed to Deliver!

Nordhaus (2015, *American Economics Review*)

Notwithstanding this progress, it has up to now proven difficult to induce countries to join in an international agreement with significant reductions in emissions. The fundamental reason is the strong incentives for free-riding in current international climate agreements. *Free-riding* occurs when a party receives the benefits of a public good without contributing to the costs. In the case of the international climate-change policy, countries have an incentive to rely on the emissions reductions of others without taking proportionate domestic abatement. To this is

Two Proposals Going Forward

Proposal #1: Use trade policy as a 2nd best solution

- Climate-conscious governments can use trade policy (i.e., carbon tariffs) to influence transboundary carbon emissions.
- Example: EU's carbon tariffs can lower carbon emissions in Asia.

Proposal #2: Use trade penalties to enforce climate cooperation

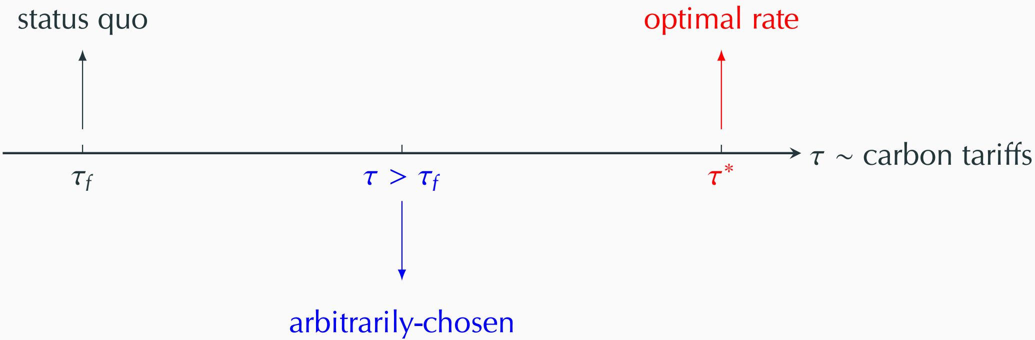
- Climate-conscious governments can form a ***Climate Club.***
- Members of the Climate Club can use collective trade penalties to prompt non-members to join the club.

Existing Assessments of Proposals #1 and #2

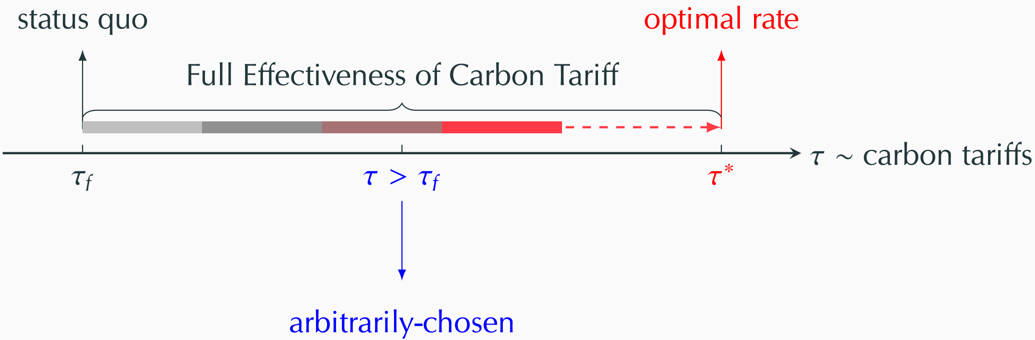
- Multiple studies have analyzed some variation of *Proposals #1* and *#2*.
- Existing studies, though, exhibit some limitations:

1. Theoretical studies often overlook firm-delocation in response to policy, scale economies in abatement, and multilateral carbon leakage.
2. Quantitative studies often analyze arbitrarily-chosen (*i.e.*, sub-optimal) carbon tariffs or trade sanctions $\longrightarrow$ cannot identify the full effectiveness of Proposals 1 and 2.

Quantitative Assessments of Proposals #1 and #2



The Trade Literature



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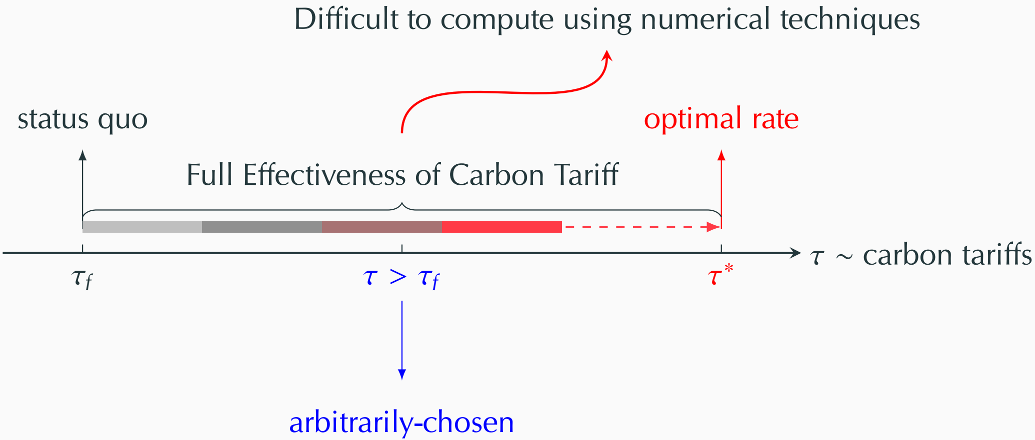

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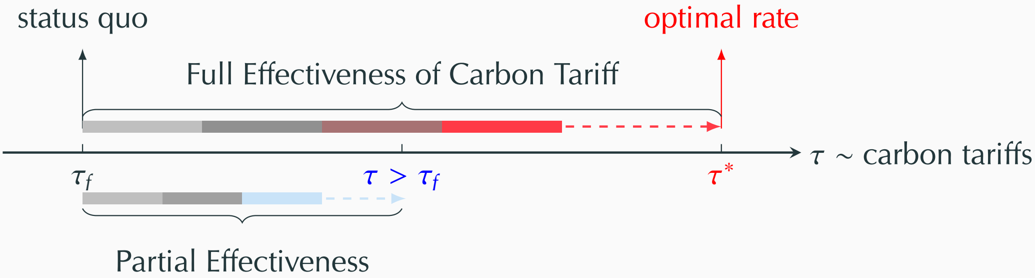

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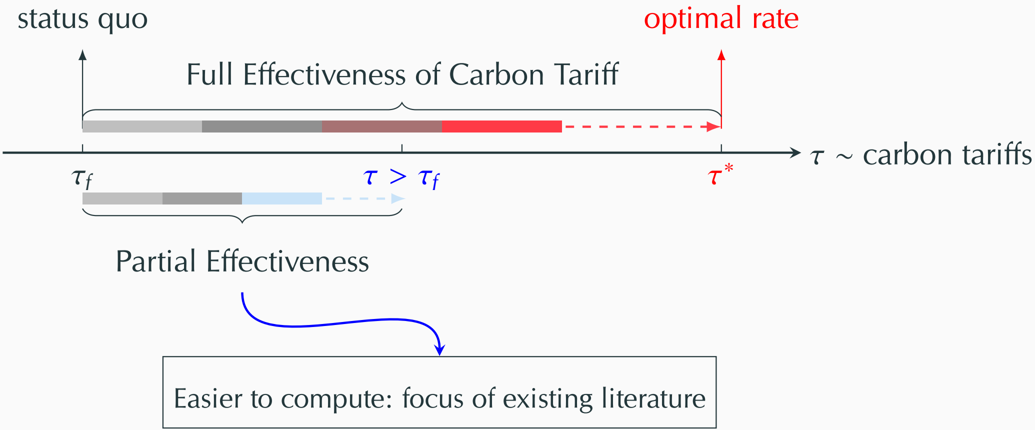

This Paper: *Contribution to the Literature*

- We develop a GE multi-industry, multi-country model of trade with transboundary carbon externality and scale economies in production/abatement.
- We derive simple analytic formulas for optimal *local carbon taxes* and *border adjustment carbon tariffs*.
- We use our analytic tax formulas to the following ends:
  1. Uncover previously-unknown trade-offs facing carbon tariffs
  2. Bypass computational obstacles that have impeded the previous literature $\longrightarrow$ uncover the full-effectiveness of Proposals #1 and #2.

Theoritical Framework

The Economic Environment

- Many countries: $i, j, n = 1, \ldots, \mathcal{N}$
  - Country i is populated by L_i workers, each of whom supplies one unit of labor.
  - Labor is the sole factor of production
- Many industries: $k, g = 1, \ldots, \mathcal{K}$
  - Each industry is served by many firms (index ω)
- Market structure: monopolistic competition + free entry
  - Free entry creates industry-level economies of scale

Notation: Good's Indexes

– Goods are indexed by origin–destination–industry

$$\text{good } ij,k \;\sim\; \text{origin } i - \text{destination } j - \text{industry } k$$

– Aggregate *supply-side* variables are indexed by origin–industry

$$\text{subscript } i,k \;\sim\; \text{origin } i - \text{industry } k$$

– Aggregate *demand-side* variables are indexed by destination–industry

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Preferences: Non-Parametric Across Industries

- Representative consumer's problem in country i

national income

$$V_i\left(\tilde{\mathbf{P}}_i, Y_i\right) = \max_{\mathbf{Q}_i} \; U_i\left(\mathbf{Q}_i\right) \qquad s.t. \; \sum_k \left(\tilde{P}_{i,k} Q_{i,k}\right) = Y_i$$

  - $\mathbf{Q}_i \equiv \{Q_{i,k}\}$ ~ composite industry-level consumption.
  - $\tilde{\mathbf{P}}_i \equiv \{\tilde{P}_{i,k}\}$ ~ "consumer" price index of industry-level composite.

- The Marshallian demand function for *industry* k goods in *market* i

$$Q_{i,k} = \mathcal{D}_{i,k}\left(\tilde{\mathbf{P}}_i, Y_i\right)$$

- The **Cobb-Douglas** case: $U_i\left(\mathbf{Q}_i\right) = \prod_{k=1}^{\mathcal{K}} Q_{i,k}^{e_{i,k}} \longrightarrow Q_{i,k} = e_{i,k} Y_i / \tilde{P}_{i,k}$

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- Cross-national aggregator: $Q_{i,k} = \left(\sum_{j \in \mathbb{C}} Q_{ji,k}^{\frac{\sigma_k - 1}{\sigma_k}} \right)^{\frac{\sigma_k}{\sigma_k - 1}}$

- Sub-national aggregator: $Q_{ji,k} = \left(\sum_{\omega \in \Omega_{j,k}} q_{ji,k}(\omega)^{\frac{\gamma_k - 1}{\gamma_k}} \right)^{\frac{\gamma_k}{\gamma_k - 1}}$

- The demand facing an firm-level variety ω (origin j–destination i–industry k):

$$q_{ji,k}(\omega) = \left(\frac{\tilde{p}_{ji,k}(\omega)}{P_{ji,k}} \right)^{-\gamma_k} \left(\frac{\tilde{P}_{ji,k}}{P_{i,k}} \right)^{-\sigma_k} \mathcal{D}_{i,k}\left(\tilde{\mathbf{P}}_i, Y_i \right)$$

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price index (origin j–destination i–industry$k$)

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Production and Firms

- Firms compete under monopolistic competition and free entry
- A firm located in *origin i–industry k* faces the following costs:
  1. Entry cost: $w_i f^e_{i,k}$
  2. Production/delivery cost per unit of output: $\dfrac{\tau_{ij,k} w_i}{\varphi_{i,k}(\omega)}$
  3. Abatement cost: a fraction $a_{i,k}(\omega)$ of inputs are allocated to abatement

- CO_2 emission per unit of output $= \left[1 - a_{i,k}(\omega)\right]^{\frac{1}{\alpha_k} - 1}$

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emission elasticity

Summarizing the Production Side

- We can summarize the *producer* price and CO_2 emission associated with *origin i–industry k* as a function of total output, $\mathcal{Q}_{i,k} \equiv \sum_{j \in \mathbb{C}} d_{ij,k} Q_{ij,k}$, and abatement, $a_{i,k}$:

$$\text{[producer price]} \qquad P_{ij,k} = \bar{d}_{ij,k} \bar{p}_{ii,k} w_i (1 - a_{i,k})^{\frac{1}{\gamma_k} - 1} \mathcal{Q}_{i,k}^{-\frac{1}{\gamma_k}}$$

$$[CO_2 \text{ emission}] \qquad Z_{i,k} = \bar{z}_{i,k} (1 - a_{i,k})^{\frac{1}{\alpha_k} + \frac{1}{\gamma_k} - 1} \mathcal{Q}_{i,k}^{1 - \frac{1}{\gamma_k}}$$

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Instruments of Policy

– From country i's perspective, the market equilibrium is inefficient for 3 reasons:

1. Firms do not internalize their carbon externality
2. Industries exhibit differential markups $\longrightarrow$ misallocation
3. There is unexploited export/import market power vis-à-vis the rest of the world.

– Governments have access to a complete set of policy instruments $\longrightarrow$ they can correct all the inefficiencies listed above and reach the *1st-best* outcome.

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Instruments of Policy

- Import tariffs, export subsidies, and industrial subsidies create a wedge b/w *producer prices* (P) and *consumer prices* ($\tilde{P}$):

$$\tilde{P}_{ij,k} = \frac{1 + \boldsymbol{t_{ij,k}}}{(1 + \boldsymbol{x_{ij,k}})(1 + \boldsymbol{s_{i,k}})} P_{ij,k}$$

- Carbon taxes regulate abatement:

$$\text{Carbon tax} \sim \boldsymbol{\tau_{i,k}} \xrightarrow{\text{cost minimization}} (1 - a_{i,k}) = \left(\frac{\alpha_k}{1 - \alpha_k}\right)^{\alpha_k} \left(\frac{w_i / \bar{\varphi}_{i,k}}{\boldsymbol{\tau_{i,k}}}\right)^{\alpha_k}.$$

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Equilibrium for a given Vector of Taxes $(\mathbf{t}, \mathbf{x}, \mathbf{s}, \boldsymbol{\tau})$

1. Consumption choices are optimal: $\begin{cases} Q_{ji,k} = \mathcal{D}_{ji,k}(Y_i, \tilde{\mathbf{P}}_i) \\ \tilde{P}_{ji,k} = \frac{1+t_{ji,k}}{(1+x_{ji,k})(1+s_{j,k})} P_{ji,k} \end{cases}$

2. Production choices are optimal: $\begin{cases} P_{ij,k} = \bar{d}_{ij,k}\bar{p}_{ii,k} w_i (1-a_{i,k})^{\frac{1}{\gamma_k}-1} \mathcal{Q}_{i,k}^{-\frac{1}{\gamma_k}} \\ (1-a_{i,k}) = \left(\frac{\alpha_k}{1-\alpha_k}\right)^{\alpha_k} \left(\frac{w_i/\bar{\varphi}_{i,k}}{\tau_{i,k}}\right)^{\alpha_k} \end{cases}$

3. Wage payments equal net sales: $w_i L_i = \sum_{j=1}^{\mathcal{N}} \sum_{k=1}^{\mathcal{K}} \left[(1-\alpha_k \frac{\gamma_k - 1}{\gamma_k}) P_{ij,k} Q_{ij,k}\right]$

4. Income equals wage payments plus tax revenues: $Y_i = w_i L_i + \mathcal{R}_i(\mathbf{t}, \mathbf{x}, \mathbf{s}, \boldsymbol{\tau})$

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tax revenues

National Welfare

- Let $\mathbb{T}_i \equiv (\mathbf{t}_i, \mathbf{x}_i, \mathbf{s}_i, \boldsymbol{\tau}_i)$ denote country i's vector of taxes, and let $\mathbb{T} \equiv (\mathbb{T}_i, \mathbb{T}_{-i})$ denote the global vector of taxes.
- Welfare in country i is the sum of the indirect utility from consumption and the disutility from ***global*** CO_2 emissions:

$$W_i(\mathbb{T}) \equiv \underbrace{V_i\left(Y_i(\mathbb{T}), \tilde{\mathbf{P}}_i(\mathbb{T})\right)}_{\text{utility from consumption}} - \underbrace{\sum_{n=1}^{\mathcal{N}} \sum_{k=1}^{\mathcal{K}} \delta_{ni,k} Z_{n,k}(\mathbb{T})}_{\text{disutility from } CO_2}$$

National Welfare

- Let $\mathbb{T}_i \equiv (\mathbf{t}_i, \mathbf{x}_i, \mathbf{s}_i, \boldsymbol{\tau}_i)$ denote country i's vector of taxes, and let $\mathbb{T} \equiv (\mathbb{T}_i, \mathbb{T}_{-i})$ denote the global vector of taxes.

- Welfare in country i is the sum of the indirect utility from consumption and the disutility from ***global*** CO_2 emissions:

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Country i's Optimal Policy Problem

– A non-cooperative government's optimal policy $\mathbb{T}_i^\star \equiv (\mathbf{t}_i^\star, \mathbf{x}_i^\star, \mathbf{s}_i^\star, \boldsymbol{\tau}_i^\star)$ maximizes national welfare taking taxes in the RoW as given:

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– The unilaterally optimal policy does *not* internalize:

1. Country i's carbon externality on the rest of the world
2. Country i's terms-of-trade externality on the rest of the world

Summary of Theoretical Approach

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Theorem: *Country i's Unilaterally Optimal Policy*

[carbon tax] $\tau^{\star}_{i,k} = \tau^{\star}_{i} = \tilde{\delta}_{ii}$

[industrial subsidy] $1 + s^{\star}_{i,k} = \dfrac{\gamma_k}{\gamma_k - 1}$

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CO$_2$ per dollar vlaue

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Constant-Returns to Scale ($\gamma_k \to \infty$)

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$\boxed{-1 - (\sigma_k - 1)(1 - \lambda_{ij,k})}$

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A Summary of Our Optimal Policy Result

- Local carbon taxes are uniform across industries.
- Industrial subsidies are carbon-blind: They solely restore marginal cost-pricing.
- $\text{Cov}(\nu_k, 1/\gamma_k) > 0 \longrightarrow$ scale effects diminish the effectiveness of carbon tariffs.
- $\text{Cov}(\nu_k, 1/\sigma_k) < 0 \longrightarrow$ **ToT-optimal** trade policy exhibits environmental bias.

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Global Climate Cooperation

Optimal Cooperative Policy

- Perviously, we characterized optimal policy for a non-cooperative government.
- Now, suppose governments act *cooperatively* to maximize global welfare.
- The optimal policy choice under *global climate cooperation* is the following:

$$[\text{carbon tax}] \qquad \tau^*_{i,k} = \tau^*_i = \sum_{j \in \mathbb{C}} \tilde{P}_j \delta_{ij}$$

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internalizes carbon externality across all locations

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Mapping Theory to Data

Sketch of Optimization-Free Quantitative Strategy

– Our goal is to simulate the counterfactual equilibrium under optimal policy.

– A bullet point summary of our quantitative strategy:

1. Use hat-algebra notation $\longrightarrow$ express optimal tax formulas in changes
2. Use hat-algebra notation $\longrightarrow$ express equilibrium conditions in changes
3. Solve the system of equations derived under Steps (1) and (2)

– Step (3) determines the change in *welfare* and CO_2 *emissions* in response to optimal policy as a function of the following *sufficient statistics*:

$$\mathcal{B}_v \equiv \{\lambda_{ni,k}, e_{n,k}, r_{ni,k}, \rho_{i,k}, \tilde{\delta}_{ni}, w_n\bar{L}_n, Y_n\}_{ni,k} \qquad \mathcal{B}_e = \{\sigma_k, \gamma_k, \alpha_k\}_k$$

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precieved cost of CO_2

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national accounts data

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estimable parameters

Data on Trade, Production, and CO_2 Emissions

Data on trade and production

- *Source*: 2009 World Input-Output Database (WIOD).
- 33 Countries + an aggregate of the rest of the world
- 19 broadly-defined Industries

Data on CO_2 emissions

- *Source*: 2009 WIOD environmental accounts.
- We calculate CO_2 equivalent emissions based on global warming potential:

$$Z = Z_{\mathrm{CO2}} + 28 \times Z_{\mathrm{CH4}} + 265 \times Z_{\mathrm{N2O}}$$

Estimating Structural Elasticities

Emission Elasticity ~ α_k Estimated Values

- We infer $\alpha_{i,k}$ from applied carbon taxes and CO_2 intensities:

$$\text{cost minimization} \longrightarrow \alpha_{i,k} = \frac{\gamma_k}{\gamma_k - 1}\tau_{i,k} v_{i,k}$$

- Data on $\tau_{i,k}$ are from EUROSTAT and OECD-PINE.

Markup ~ $\gamma_k/(\gamma_k - 1)$

- We estimate $\frac{\gamma_k}{\gamma_k - 1}$ using De Loecker's (2012, *AER*) methodology.
- Data on firms' financial accounts are from COMPUSTAT.

Trade Elasticity ~ σ_k

- We use the trade elasticities estimated by Caliendo & Parro (2014, *ReStud*)
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Main Quantitative Findings

The Effectiveness of EU's Unilateral Policy

- Consider a scenario where the E.U. implements its unilaterally optimal policy, $\mathbb{T}^{\star}_{\mathrm{EU}}$, and the rest of the world is passive.

- EU's avg. border-adjustment carbon tariffs on imports $\simeq$ **3.5%** Graphical Illustration

- EU's avg. border-adjustments carbon subsidy to export $\simeq$ **3.8%** Graphical Illustration

- Global CO_2 emissions will go down by a modest **0.4%**

The Non-cooperative Nash Equilibrium

- Suppose all countries *non-cooperatively* and *simultaneously* erect their optimal border-adjustment carbon tariffs/subsidies (as part of $\mathbb{T}_i^\star$).
- Global CO_2 emissions will go down by **3.1%** $\simeq$ **3.2%** of the CO_2 reduction possible under global climate cooperation (*i.e.*, $^{3.1}/_{95.5}\%$).
- The average country loses more than **16%** of it CO_2-adjusted real GDP under the non-cooperative Nash equilibrium.
- Under global climate cooperation the average country gains **44%** in terms of CO_2-adjusted real GDP.

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The Consequences of Non-Cooperative Policies: *Select Countries*

	Increasing Returns to Scale				Constant Returns to Scale			
	Non-Cooperative		Global Cooperation		Non-Cooperative		Global Cooperation	
Country	ΔCO2	ΔW	ΔCO2	ΔW	ΔCO2	ΔW	ΔCO2	ΔW
EU	0.0%	-32.2%	-91.1%	85.8%	-0.7%	1.9%	-91.2%	83.7%
BRA	-8.8%	-19.2%	-95.7%	73.8%	-8.3%	1.5%	-95.3%	72.2%
CHN	1.9%	-5.3%	-97.0%	18.8%	0.8%	0.5%	-97.1%	18.3%
MEX	-0.6%	-8.0%	-95.6%	23.1%	-3.7%	-2.9%	-95.9%	20.5%
USA	0.1%	-13.4%	-95.4%	34.3%	-1.5%	0.3%	-95.6%	32.8%
Global	-3.1%	-16.5%	-95.5%	44.0%	-3.3%	-0.9%	-95.6%	42.4%

Cross-national differences in welfare gains and CO_2 reduction are driven by

- differences in market power *vis-a-vis* the RoW
- differences in disutility from CO_2 emissions

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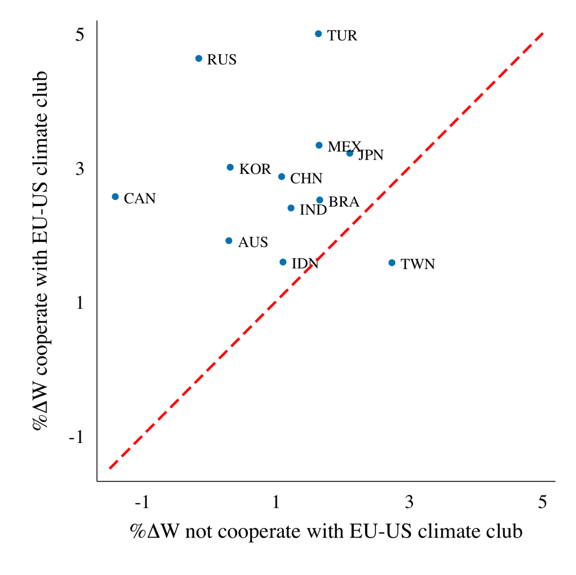
The Efficacy of Trade Penalties in a Climate Club Model



Summary of Findings

- Non-cooperative border adjustment carbon tariffs/subsidies have a modest effect on global CO_2 emissions.
- Overlooking *scale economies* or *firm-delocation* overstates the efficacy of carbon tariffs at reducing CO_2 emissions.
- The Climate Club model with optimal trade penalties looks promising.
- **Ongoing work:** We are analyzing the Climate Club model in greater depth.

Thank You.

Our Dual Approach to Characterizing $\mathbb{T}^\star$

1. Use duality + reformulate the optimal policy problem as one where the government chooses the optimal vector of prices linked to its economy (rather than directly choosing trade taxes).

2. Use standard envelope conditions (e.g., *Roy's identity*, *Shephard's lemma*) + derive additional envelope conditions that indicate wage and circular income effects are welfare-neutral at the optimum.

3. Use the primitive properties of Marshallian demand functions (i.e., *Cournot aggregation*, *homogeneity of degree zero*) to establish uniqueness of the optimal policy schedule. Return

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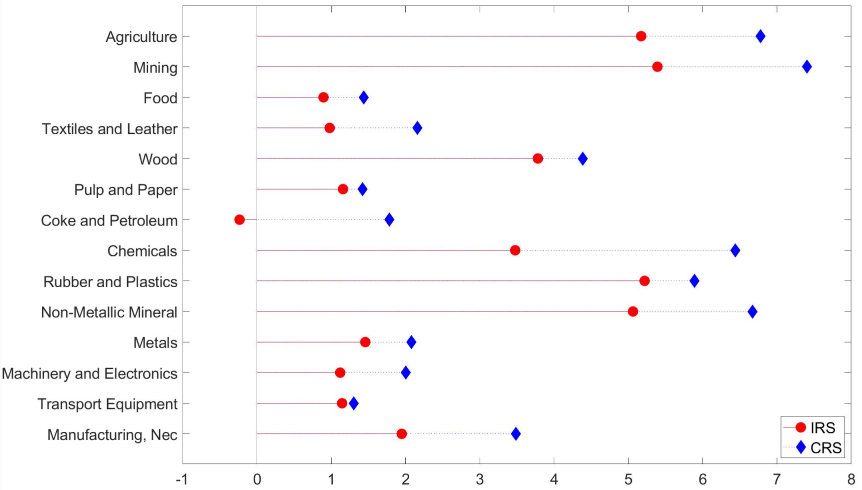
E.U.'s Optimal Import Tariff Schedule



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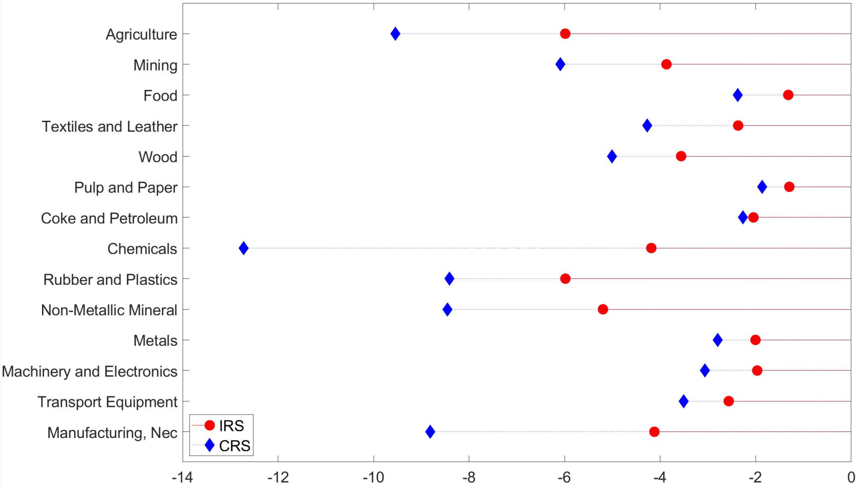
E.U.'s Optimal Export Subsidy Schedule



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Estimated Elasticities: *WIOD Industry Categories 1-9*

	Industry	Carbon Intensity (v)	Emission Elasticity (α)	Trade Elasticity (σ)	Markup ($\frac{\gamma}{\gamma-1}$)
1	Agriculture	1,589	0.044	8.11	1.464
2	Mining	1,372	0.025	15.72	1.529
3	Food	84	0.011	2.55	1.698
4	Textile	81	0.011	5.56	2.109
5	Wood	109	0.014	10.83	1.278
6	Paper	135	0.008	9.07	1.296
7	Refined Petroleum	376	0.015	51.08	1.178
8	Chemicals	295	0.032	4.75	2.064
9	Plastics	50	0.010	1.66	1.272

Estimated Elasticities: *WIOD Industry Categories 10-19*

	Industry	Carbon Intensity (v)	Emission Elasticity (α)	Trade Elasticity (σ)	Markup ($\frac{\gamma}{\gamma-1}$)
10	Nonmetallic Minerals	1,422	0.026	2.76	1.488
11	Metals	372	0.009	6.14	1.239
12	Electronics & Machinery	26	0.007	6.06	1.501
13	Motor Vehicles	30	0.006	0.69	1.211
14	Other Manufacturing	46	0.012	5	1.913
15	Electricity, Gas and Water	3,791	0.021	5	1.119
16	Construction	39	0.012	5	1.098
17	Retail and Wholesale	37	0.018	5	1.137
18	Transportation	503	0.059	5	1.011
19	Other Services	63	0.009	5	1.596

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