Can Trade Policy Mitigate Climate Change?

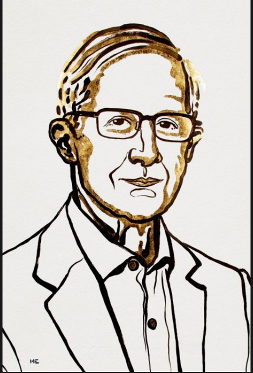
Farid Farrokhi (Purdue)   Ahmad Lashkaripour (Indiana University)

LSE Environment Week, September 2023

Background

Existing Climate Agreements Have Failed to Deliver!

Cause of Failure: *The Free-Riding Problem*



Nordhaus (2015, *AER*)

"The fundamental reason is the strong incentives for free-riding in current international climate agreements [...] Many countries have an incentive to rely on the emissions reductions of others without taking proportionate domestic abatement."

Two Remedies for the *Free-Riding* Problem

Proposal #1: **Carbon Border Taxes**

- governments can use *carbon border taxes* as a *2nd-best* policy to curb (untaxed) CO_2 emissions beyond their jurisdiction
- the idea is to mimic 1st-best carbon pricing via border taxes

Proposal #2: **Climate Club**

- climate-conscious governments can forge a club and use *collective* and *contingent* trade penalties to deter free-riding.
- has the potential to achieve *1st-best* carbon-pricing

Two Remedies for the *Free-Riding* Problem

Proposal #1: **Carbon Border Taxes**

- governments can use *carbon border taxes* as a *2nd-best* policy to curb (untaxed) CO_2 emissions beyond their jurisdiction
- the idea is to mimic 1st-best carbon pricing via border taxes

Proposal #2: **Climate Club**

- climate-conscious governments can forge a club and use *collective* and *contingent* trade penalties to deter free-riding.
- has the potential to achieve *1st-best* carbon-pricing & free trade!

Existing Assessments of Climate-Oriented Trade Policy

- We have a limited understanding of the efficacy of Proposals #1 & #2

- Computing the *maximal* efficacy of theses proposals is challenging:
    - infeasible with brute numerical optimization given high-dimensionality
    - theoretical representations of optimal policy can help, but existing theories are too stylized to guide quantitative analysis

Existing Assessments of Climate-Oriented Trade Policy

- We have a limited understanding of the efficacy of Proposals #1 & #2
- Computing the *maximal* efficacy of theses proposals is challenging:
  - infeasible with brute numerical optimization given high-dimensionality
  - theoretical representations of optimal policy can help, but existing theories are too stylized to guide quantitative analysis
  - past literature analyzes simplified variants of these proposals that can be easily quantified but are suboptimal $\longrightarrow$ unable to determine maximal efficacy

Related Literature

This Paper

1. Develop a rich model of trade with climate externalities
   - general equilibrium + multi-industry + multi-country
   - global energy markets → carbon supply chains

This Paper

1. Develop a rich model of trade with climate externalities
    - general equilibrium + multi-industry + multi-country
    - global energy markets → carbon supply chains
2. Derive analytical formulas for optimal *carbon border taxes* & *climate club penalties* under rich GE considerations

This Paper

1. Develop a rich model of trade with climate externalities
    - general equilibrium + multi-industry + multi-country
    - global energy markets → carbon supply chains

2. Derive analytical formulas for optimal *carbon border taxes* & *climate club penalties* under rich GE considerations

3. Map model & theoretical formulas to data to uncover the maximal efficacy of two canonical climate policy proposals:
    - (Proposal 1) carbon border taxes
    - (Proposal 2) climate club

Theoritical Framework

Economic Environment

- Multiple countries: $i, n = 1, ..., N$
  - country i is endowed with $\bar{L}_i$ units of labor and $\bar{R}_i$ carbon reserves.

- Multiple industries:
  - energy: $k = 0$
  - final goods: $k = 1, ..., K$.

- All industries are perfectly competitive and tradable (*s.t.* trade costs)

Economic Environment

- Multiple countries: $i, n = 1, ..., N$
  - country i is endowed with $\bar{L}_i$ units of labor and $\bar{R}_i$ carbon reserves.
- Multiple industries:
  - energy: $k = 0$
  - final goods: $k = 1, ..., K$.
- All industries are perfectly competitive and tradable (*s.t.* trade costs)
- CO_2 emissions are determined by energy usage

Consumption

- Non-parametric utility aggregator across international varieties

$$\text{variety } ni,k \;\sim\; \text{origin } n\text{–destination } i\text{–industry } k$$

- Demand for each variety is a function of
  1. expendable income: E_i
  2. after tax prices: $\tilde{\mathbf{P}}_i = \left\{ \tilde{P}_{1i,k}, ..., \tilde{P}_{Ni,k} \right\}_{k=1,...,K}$

Consumption

- Non-parametric utility aggregator across international varieties

variety $ni, k \; \sim$ origin n–destination i–industry k

- Demand for each variety is a function of

1. expendable income: E_i
2. after tax prices: $\tilde{\mathbf{P}}_i = \left\{ \tilde{P}_{1i,k}, \ldots, \tilde{P}_{Ni,k} \right\}_{k=1,\ldots,K}$

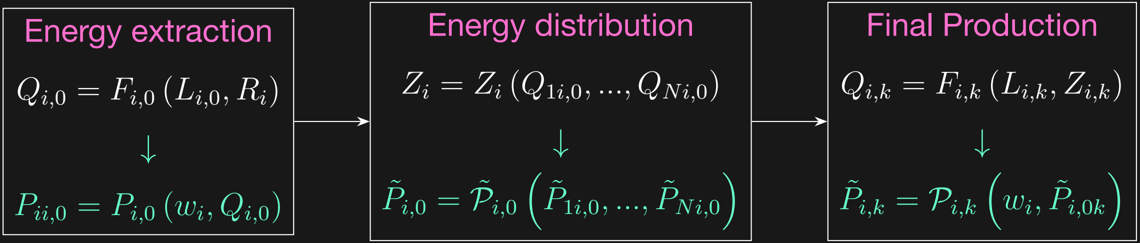
$$\boxed{\text{indirect utility} \sim V_i \left(E_i, \tilde{\mathbf{P}}_i \right)}$$

Production: Energy + Final Goods

- Energy $(k = 0)$ extraction uses labor ($L_{i,0}$) and energy reserves ($\bar{R}_i$)
- A distributor aggregates energy varieties from various locations, $Z_i\left(Q_{1i,0}, ..., Q_{Ni,0}\right)$, and sells them to downstream producers
- Production in industry $k = 1, ..., K$ combines labor ($L_{i,k}$) and composite energy inputs ($Z_{i,k}$)

Production: Energy + Final Goods

- Energy $(k = 0)$ extraction uses labor ($L_{i,0}$) and energy reserves ($\bar{R}_i$)
- A distributor aggregates energy varieties from various locations, $Z_i\left(Q_{1i,0}, ..., Q_{Ni,0}\right)$, and sells them to downstream producers
- Production in industry $k = 1, ..., K$ combines labor ($L_{i,k}$) and composite energy inputs ($Z_{i,k}$)



Energy extraction

$$Q_{i,0} = F_{i,0}\left(L_{i,0}, R_i\right)$$

$$\downarrow$$

$$P_{ii,0} = P_{i,0}\left(w_i, Q_{i,0}\right)$$

Energy distribution

$$Z_i = Z_i\left(Q_{1i,0}, ..., Q_{Ni,0}\right)$$

$$\downarrow$$

$$\tilde{P}_{i,0} = \tilde{\mathcal{P}}_{i,0}\left(\tilde{P}_{1i,0}, ..., \tilde{P}_{Ni,0}\right)$$

Final Production

$$Q_{i,k} = F_{i,k}\left(L_{i,k}, Z_{i,k}\right)$$

$$\downarrow$$

$$\tilde{P}_{i,k} = \mathcal{P}_{i,k}\left(w_i, \tilde{P}_{i,0k}\right)$$

Social Welfare and Rationales for Policy Intervention

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

$$W_i \equiv \underbrace{V_i\left(E_i, \tilde{\mathbf{P}}_i\right)}_{\text{consumption utility}} - \overbrace{\delta_i \sum_{n=1}^{N} \sum_{k=1}^{K} Z_{n,k}}^{\text{disutility from CO}_2}$$

Social Welfare and Rationales for Policy Intervention

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

disutility per tonne of CO_2

$$W_i \equiv \quad V_i(E_i, \tilde{\mathbf{P}}_i) \quad - \quad \delta_i \sum_{n=1}^{\mathcal{N}} \sum_{k=1}^{\mathcal{K}} Z_{n,k}$$

Social Welfare and Rationales for Policy Intervention

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

disutility per tonne of CO_2

$$W_i \equiv V_i(E_i, \tilde{\mathbf{P}}_i) - \delta_i \sum_{n=1}^{\mathcal{N}} \sum_{k=1}^{\mathcal{K}} Z_{n,k}$$

CO_2 emissions from origin n–industry k

Social Welfare and Rationales for Policy Intervention

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

$$W_i \equiv \quad V_i(E_i, \tilde{\mathbf{P}}_i) \quad - \quad \delta_i \sum_{n=1}^{\mathcal{N}} \sum_{k=1}^{\mathcal{K}} Z_{n,k}$$

Two rationales for policy intervention from country i's standpoint:

1. firms do not internalize their CO_2 externality on country i's residents
2. firms do not internalize their collective market power $\longrightarrow$ unexploited terms-of-trade (ToT) gains

Unilaterally Optimal *vs.* Efficient Policy

- Unilaterally Optimal Policy (max W_i)
  - carbon tax: $\tau_i^* \equiv \tilde{P}_{i,k0} - \tilde{P}_{i,0} = \tilde{\delta}_i$
  - border taxes: manipulate ToT + tax foreign CO_2 emissions

Unilaterally Optimal *vs.* Efficient Policy

- Unilaterally Optimal Policy (max W_i)
  - carbon tax: $\tau^*_{i,k} = \tilde{\delta}_i$
  - border taxes: manipulate ToT + tax foreign CO_2 emissions

- Efficient policy from a global standpoint (max $\sum_n \vartheta_n W_n$)
  - carbon tax: $\tau^\star = \sum_n \tilde{\delta}_n$
  - zero border taxes + lump-sum international transfers

Unilaterally Optimal *vs.* Efficient Policy

- Unilaterally Optimal Policy (max W_i)
  - carbon tax: $\tau_{i,k}^{*} = \tilde{\delta}_i$
  - border taxes: manipulate ToT + tax foreign CO_2 emissions

- Efficient policy from a global standpoint (max $\sum_n \vartheta_n W_n$)
  - carbon tax: $\tau^{\star} = \sum_n \tilde{\delta}_n$
  - zero border taxes + lump-sum international transfers

Theorem: the GE elasticities of wage and demand quantities *w.r.t.* policy are redundant for optimal policy design $\longrightarrow$ the optimal policy can be derived without formally characterizing these complex elasticities.

The Free-Riding Problem

- Free-riding occurs because the *unilaterally* optimal carbon tax is lower than the *globally* optimal rate

$$\underbrace{\tau_i^* = \tilde{\delta}_i}_{\text{unilaterally optimal}} \quad < \quad \overbrace{\tau^* = \sum_n \tilde{\delta}_n}^{\text{globally optimal}}$$

The Free-Riding Problem

- Free-riding occurs because the *unilaterally* optimal carbon tax is lower than the *globally* optimal rate

$$\underbrace{\tau_i^* = \tilde{\delta}_i}_{\text{unilaterally optimal}} < \overbrace{\tau^* = \sum_n \tilde{\delta}_n}^{\text{globally optimal}}$$

- Two remedies for the free-riding problem:
  1. use ***carbon border taxes*** as a 2nd-best policy to mimic τ^*
  2. forge a ***climate club*** and use collective trade penalties to deter free-riding

The Free-Riding Problem

- Free-riding occurs because the *unilaterally* optimal carbon tax is lower than the *globally* optimal rate

$$\underbrace{\tau_i^* = \tilde{\delta}_i}_{\text{unilaterally optimal}} < \overbrace{\tau^* = \sum_n \tilde{\delta}_n}^{\text{globally optimal}}$$

- Two remedies for the free-riding problem:
  1. use ***carbon border taxes*** as a 2nd-best policy to mimic τ^*
  2. forge a ***climate club*** and use collective trade penalties to deter free-riding

We use our analytic formulas for optimal ***carbon border taxes*** & ***climate club*** penalties to determine the maximal efficacy of each policy. formulas

Mapping Theory to Data

Quantitative Strategy

- Compute the counterfactual equilibrium under optimal policy:
  - (1) equilibrium allocation depends on optimal policy
  - (2) optimal policy depends on equilibrium allocation
  - jointly solve the systems of equations implied by (1) and (2).

Quantitative Strategy

- Compute the counterfactual equilibrium under optimal policy:
  - (1) equilibrium allocation depends on optimal policy
  - (2) optimal policy depends on equilibrium allocation (analytic formulas)
  - jointly solve the systems of equations implied by (1) and (2).

Quantitative Strategy

- Compute the counterfactual equilibrium under optimal policy:
  - (1) equilibrium allocation depends on optimal policy
  - (2) optimal policy depends on equilibrium allocation (analytic formulas)
  - jointly solve the systems of equations implied by (1) and (2).
- Sufficient statistics
  - data: trade, production, & CO_2 emissions $+$ applied taxes data
  - parameters: trade elasticities $+$ energy input demand elasticity $+$ $\left\{\tilde{\delta}_i\right\}_i$
    parameters

Quantitative Assessment of Proposals 1 and 2

Summary of Proposal 1

- **Proposal 1:** Governments incorporate **carbon border taxes** in their trade policy to reduce transboundary carbon emissions.
- We simulate a non-cooperative equilibrium in which governments simultaneously choose their unilaterally optimal policy, which includes
  - unilaterally optimal carbon taxes
  - carbon border taxes

Summary of Proposal 1

- **Proposal 1:** Governments incorporate **carbon border taxes** in their trade policy to reduce transboundary carbon emissions.
- We simulate a non-cooperative equilibrium in which governments simultaneously choose their unilaterally optimal policy, which includes
  - unilaterally optimal carbon taxes
  - carbon border taxes
- Governments with little care for climate damage, apply little-to-no carbon border taxes

Results: The Efficacy of Proposal 1

	Non-Cooperative						Global Cooperation (first-best)		
	Carbon + Border Tax			Carbon Tax					
Country	ΔCO_2	ΔV	ΔW	ΔCO_2	ΔV	ΔW	ΔCO_2	ΔV	ΔW
EU	-22.2%	-0.3%	-0.0%	-21.2%	-0.0%	0.2%	-38.5%	-0.4%	1.7%
Canada	8.3%	-1.6%	-1.5%	3.5%	-0.1%	0.0%	-42.6%	-1.2%	-0.6%
China	-9.7%	-0.1%	0.1%	-8.3%	0.0%	0.1%	-39.0%	-1.7%	-0.6%
Indonesia	1.7%	-0.2%	-0.1%	2.4%	-0.0%	0.1%	-42.9%	-3.1%	-2.7%
Japan	-2.2%	-0.3%	-0.1%	-0.6%	0.0%	0.1%	-39.1%	-1.5%	-0.5%
Russia	7.3%	-1.3%	-1.3%	3.5%	-0.2%	-0.2%	-43.8%	-0.0%	0.1%
Saudi Arabia	12.2%	-3.9%	-3.9%	4.8%	-0.6%	-0.6%	-45.8%	-0.6%	-0.5%
USA	-3.8%	-0.3%	-0.3%	-1.9%	0.0%	0.0%	-43.0%	-1.7%	-1.3%
Global	-6.5%	-0.5%	-0.2%	-5.4%	-0.0%	0.2%	-41.0%	-0.6%	1.1%

Results: The Efficacy of Proposal 1

	Non-Cooperative						Global Cooperation		
	Carbon + Border Tax			Carbon Tax			(first-best)		
Country	ΔCO_2	ΔV	ΔW	ΔCO_2	ΔV	ΔW	ΔCO_2	ΔV	ΔW
EU	-22.2%	-0.3%	-0.0%	-21.2%	-0.0%	0.2%	-38.5%	-0.4%	1.7%
Canada	8.3%	-1.6%	-1.5%	3.5%	-0.1%	0.0%	-42.6%	-1.2%	-0.6%
China	-9.7%	-0.1%	0.1%	-8.3%	0.0%	0.1%	-39.0%	-1.7%	-0.6%
Indonesia	1.7%	-0.2%	-0.1%	2.4%	-0.0%	0.1%	-42.9%	-3.1%	-2.7%
Japan	-2.2%	-0.3%	-0.1%	-0.6%	0.0%	0.1%	-39.1%	-1.5%	-0.5%
Russia	7.3%	-1.3%	-1.3%	3.5%	-0.2%	-0.2%	-43.8%	-0.0%	0.1%
Saudi Arabia	12.2%	-3.9%	-3.9%	4.8%	-0.6%	-0.6%	-45.8%	-0.6%	-0.5%
USA	-3.8%	-0.3%	-0.3%	-1.9%	0.0%	0.0%	-43.0%	-1.7%	-1.3%
Global	-6.5%	-0.5%	-0.2%	-5.4%	-0.0%	0.2%	-41.0%	-0.6%	1.1%

Results: The Efficacy of Proposal 1

	Non-Cooperative						Global Cooperation (first-best)		
	Carbon + Border Tax			Carbon Tax					
Country	ΔCO_2	ΔV	ΔW	ΔCO_2	ΔV	ΔW	ΔCO_2	ΔV	ΔW
EU	-22.2%	-0.3%	-0.0%	-21.2%	-0.0%	0.2%	-38.5%	-0.4%	1.7%
Canada	8.3%	-1.6%	-1.5%	3.5%	-0.1%	0.0%	-42.6%	-1.2%	-0.6%
China	-9.7%	-0.1%	0.1%	-8.3%	0.0%	0.1%	-39.0%	-1.7%	-0.6%
Indonesia	1.7%	-0.2%	-0.1%	2.4%	-0.0%	0.1%	-42.9%	-3.1%	-2.7%
Japan	-2.2%	-0.3%	-0.1%	-0.6%	0.0%	0.1%	-39.1%	-1.5%	-0.5%
Russia	7.3%	-1.3%	-1.3%	3.5%	-0.2%	-0.2%	-43.8%	-0.0%	0.1%
Saudi Arabia	12.2%	-3.9%	-3.9%	4.8%	-0.6%	-0.6%	-45.8%	-0.6%	-0.5%
USA	-3.8%	-0.3%	-0.3%	-1.9%	0.0%	0.0%	-43.0%	-1.7%	-1.3%
Global	-6.5%	-0.5%	-0.2%	-5.4%	-0.0%	0.2%	-41.0%	-0.6%	1.1%

Results: The Efficacy of Proposal 1

	Non-Cooperative						Global Cooperation		
	Carbon + Border Tax			Carbon Tax			(first-best)		
Country	ΔCO_2	ΔV	ΔW	ΔCO_2	ΔV	ΔW	ΔCO_2	ΔV	ΔW
EU	-22.2%	-0.3%	-0.0%	-21.2%	-0.0%	0.2%	-38.5%	-0.4%	1.7%
Canada	8.3%	-1.6%	-1.5%	3.5%	-0.1%	0.0%	-42.6%	-1.2%	-0.6%
China	-9.7%	-0.1%	0.1%	-8.3%	0.0%	0.1%	-39.0%	-1.7%	-0.6%
Indonesia	1.7%	-0.2%	-0.1%	2.4%	-0.0%	0.1%	-42.9%	-3.1%	-2.7%
Japan	-2.2%	-0.3%	-0.1%	-0.6%	0.0%	0.1%	-39.1%	-1.5%	-0.5%
Russia	7.3%	-1.3%	-1.3%	3.5%	-0.2%	-0.2%	-43.8%	-0.0%	0.1%
Saudi Arabia	12.2%	-3.9%	-3.9%	4.8%	-0.6%	-0.6%	-45.8%	-0.6%	-0.5%
USA	-3.8%	-0.3%	-0.3%	-1.9%	0.0%	0.0%	-43.0%	-1.7%	-1.3%
Global	-6.5%	-0.5%	-0.2%	-5.4%	-0.0%	0.2%	-41.0%	-0.6%	1.1%

Results: The Efficacy of Proposal 1

- Non-cooperative carbon and border taxes

$$\Delta\text{CO}_2 = \underbrace{5.4\%}_{domestic\ tax} + \underbrace{1.1\%}_{border\ tax} = 6.5\%$$

Results: The Efficacy of Proposal 1

- Non-cooperative carbon and border taxes

$$\Delta \text{CO}_2 = \underbrace{5.4\%}_{domestic\ tax} + \underbrace{1.1\%}_{border\ tax} = 6.5\%$$

- Global climate cooperation (1st-best)

$$\Delta \text{CO}_2 = 5.4\% + 35.6\% = 41\%$$

Results: The Efficacy of Proposal 1

- Non-cooperative carbon and border taxes

$$\Delta \text{CO}_2 = \underbrace{5.4\%}_{domestic\ tax} + \underbrace{1.1\%}_{border\ tax} = 6.5\%$$

- Global climate cooperation (1st-best)

$$\Delta \text{CO}_2 = 5.4\% + 35.6\% = 41\%$$

Headline Result: non-cooperative border taxes replicate 3.1% ($\frac{1.1\%}{35.6\%}$) of the CO_2 reduction attainable under global cooperation.

Discussion: Inefficacy of Carbon Border Taxes

Three factors limit the efficacy of carbon border taxes:

1. border taxes have difficulty targeting non-traded CO_2 emissions, which constitute a large fraction of global emissions
2. carbon border taxes are not sufficiently granular to target individual firms with high carbon intensity
3. carbon leakage through GE channels
   e.g., leakage from the EU to Russia & Saudi Arabia

Summary of Proposal 2

- **Proposal 2:** a set of *core* members forge a **Climate Club**
  - *core* members move first, all other countries play simultaneously afterwards.
- Carbon pricing requirements:
  - all members must raise their carbon price to the carbon price target ($\tau^{\text{target}} \leq \tau^{\star}$)
- Accession to the Climate Club is incentivized by trade penalties:
  - free trade among club members + optimal trade penalties on non-members
  - non-members can retaliate computational challenges

The Climate Club’s Carbon Price Target

- Ideally, the carbon price target is the maximal price that yields universal participation
  - In this case the climate club will not disrupt global free trade
- The maximal carbon price target depends on the makeup of the climate club’s core members
  - a larger block of core members ⟶ more effective trade penalties ⟶ more participation to escape penalties

The Climate Club's Carbon Price Target

- Ideally, the carbon price target is the maximal price that yields universal participation
  - In this case the climate club will not disrupt global free trade
- The maximal carbon price target depends on the makeup of the climate club's core members
  - a larger block of core members $\longrightarrow$ more effective trade penalties $\longrightarrow$ more participation to escape penalties
- We measure the efficacy of the climate club for several combinations of core member

Results: EU-US Climate Club

Core members: $\{\text{EU}, \text{US}\}$

- maximal carbon price target = $53 (per tCO_2)
- Iterative rounds whereby countries join the club:
  - Round 1: Brazil, Canada, Korea, Turkey, RO Eurasia
  - Round 2: Russia, RO Americas
  - Round 3: Africa, Mexico, Saudi, Arabia, Japan
  - Round 4: China, Indonesia, RO Asia, RO Middle East
  - Round 5: Australia, India

Results: EU-US Climate Club

Core members: $\{\text{EU}, \text{US}\}$

- maximal carbon price target = \$53 (per tCO_2)
- Iterative rounds whereby countries join the club:
  - Round 1: Brazil, Canada, Korea, Turkey, RO Eurasia
  - Round 2: Russia, RO Americas
  - Round 3: Africa, Mexico, Saudi, Arabia, Japan
  - Round 4: China, Indonesia, RO Asia, RO Middle East
  - Round 5: Australia, India
- Reduction in global CO_2 emissions = 18.3%
  - compared to 6.5% (non-cooperative policies) and 41% (globally first best)

Results: Alternative Climate Club Scenarios

- Core members: $\{\text{EU}, \text{US}\}$
  - maximal carbon price target = \$53 (per tCO_2)
  - reduction in global CO_2 emissions = 18.3%

Results: Alternative Climate Club Scenarios

- Core members: $\{\text{EU}, \text{US}\}$
  - maximal carbon price target = \$53 (per tCO_2)
  - reduction in global CO_2 emissions = 18.3%
- Core members: $\{\text{EU}\}$
  - maximal carbon price target = \$37 (per tCO_2)
  - reduction in global CO_2 emissions = 13.7%

Results: Alternative Climate Club Scenarios

- Core members: $\{\text{EU}, \text{US}\}$
  - maximal carbon price target = \$53 (per tCO_2)
  - reduction in global CO_2 emissions = 18.3%
- Core members: $\{\text{EU}\}$
  - maximal carbon price target = \$37 (per tCO_2)
  - reduction in global CO_2 emissions = 13.7%
- Core members: $\{\text{EU}, \text{US}, \text{China}\}$
  - maximal carbon price target = \$90 (per tCO_2)
  - reduction in global CO_2 emissions = 28.2%

Summary of Findings

- Carbon border taxes are a poor 2nd-best policy for curbing CO_2 emissions, because
    - they cannot target less-traded but high-carbon industries
    - they are not granular enough to target individual firms

Summary of Findings

- Carbon border taxes are a poor 2nd-best policy for curbing CO_2 emissions, because
  - they cannot target less-traded but high-carbon industries
  - they are not granular enough to target individual firms
- The climate club can be highly effective at curbing CO_2 emissions...
  - but its efficacy hinges critically on (i) the make-up of core members and (ii) selecting the right target to avoid decoupling
  - China is a crucial player: a club without China is less effective and may trigger East-West decoupling

Thank You.

Related Literature

- Theories of environmental policy in an international setting
  - Unilateral policy: Markusen (1975), Copeland (1996), Hoel (1996), Kortum-Wiesbach (2022)
  - Issue linkage in international cooperation: Barrett (1997), Maggi (2016), Nordhaus (2015)
- Quantitative assessment of environmental/energy policies
  - Babiker (2005), Elliot et al (2010), Bohringer et al (2016), Larch and Wanner (2017), Farrokhi (2020), Shapiro (2020) among many others
- Optimal trade policy in general equilibrium
  - Costinot et al (2015), Bartelme et al (2022), Lashkaripour-Lugovskyy (2023)

return

Data on Observable Statistics

- Trade, production, and CO_2 emissions
  - Source: GTAP Database (2014)
  - 19 countries (13 largest countries + the EU + 5 aggregate regions) Countries
  - energy industry + 17 non-energy industries Industries
  - link energy to downstream industries via input-output tables Carbon Accounting
- Baseline taxes:
  - Import tariffs: GTAP
  - Environmentally-related Taxes: OECD-PINE

Return

Estimated Parameters

- Trade Elasticity
  - Caliendo and Parro's (2015) methodology applied to trade and tariff data
- Energy input demand elasticity
  - IV estimation of energy demand equation
- Disutility from carbon emissions, $(\tilde{\delta}_i)$
  - $\sum_i \tilde{\delta}_i \sim \text{SCC} = \$99$ per tCO_2 for 2014 (latest EPA report)
  - Recover $\tilde{\delta}_i$, by revealed preferences of governments, from environmentally-related taxes

Return

	Industry	Emissions (as % of sum)	Trade/GDP Ratio	Carbon Intensity	Carbon Cost Share	Trade Elasticity
1	Agriculture	4.2%	8.8%	100.0	0.031	2.13
2	Other Mining	1.9%	27.3%	181.4	0.057	2.13
3	Food	3.3%	8.0%	45.9	0.016	3.54
4	Textile	1.9%	22.6%	59.7	0.021	5.69
5	Wood	0.5%	8.4%	61.0	0.027	5.94
6	Paper	2.1%	8.8%	125.9	0.062	5.94
7	Chemicals	9.5%	21.9%	179.6	0.064	9.05
8	Plastics	1.8%	13.5%	89.0	0.056	9.05
9	Nonmetallic Minerals	8.6%	5.8%	458.0	0.125	14.5
10	Metals	14.7%	14.9%	205.0	0.068	14.5
11	Electronics and Machinery	3.0%	30.0%	42.1	0.023	4.57
12	Motor Vehicles	1.2%	23.4%	34.0	0.014	1.93
13	Other Manufacturing	0.6%	21.8%	41.7	0.032	1.93
14	Construction	1.5%	0.6%	59.2	0.026	5.69
15	Wholesale and Retail	3.6%	2.4%	34.7	0.017	5.69
16	Transportation	27.3%	10.5%	498.0	0.176	5.69
17	Other Services	14.5%	3.1%	26.6	0.012	5.69

Return

		Share of World Output	Share of World	Emission per capita	Emission Intensity	Disutility (% of the sum)
1	Australia (AUS)	1.8%	1.2%	239.9	146.8	1.0%
2	EU	25.9%	11.7%	100.0	100.0	34.0%
3	Brazil (BRA)	2.8%	1.7%	38.8	135.3	3.9%
4	Canada (CAN)	1.9%	1.5%	199.1	175.6	0.8%
5	China (CHN)	17.7%	30.3%	102.9	377.9	13.4%
6	Indonesia (IDN)	1.0%	1.4%	25.9	302.2	0.3%
7	India (IND)	2.4%	6.8%	24.4	618.8	8.0%
8	Japan (JPN)	6.2%	3.6%	129.5	127.7	3.8%
9	Korea (KOR)	2.2%	1.9%	169.5	189.2	2.0%
10	Mexico (MEX)	1.4%	1.4%	52.0	218.7	0.2%
11	Russia (RUS)	1.9%	3.8%	121.8	436.1	0.1%
12	Saudi Arabia (SAU)	0.4%	1.3%	195.1	750.0	0.0%
13	Turkey (TUR)	1.0%	1.1%	67.3	245.5	3.1%
14	USA	20.4%	15.0%	217.7	161.7	4.3%
15	Africa	2.6%	3.4%	13.7	286.0	14.2%
16	RO Americas	3.0%	2.6%	41.5	194.8	6.3%
17	RO Asia and Oceania	5.1%	5.9%	31.7	253.2	4.2%
18	RO Eurasia	0.7%	2.0%	68.3	674.5	0.1%
19	RO Middle East	1.6%	3.5%	78.5	493.4	0.2%

Return

Proposal 2: Computational Challenges

Characterizing all Nash equilibria faces two major challenges:

1. Computing optimal trade penalties is strenuous with numerical optimization
   - Our analytical formulas for optimal trade penalties help overcome this challenge.
2. Nash outcomes must be identified over 2^N possible outcomes.[1]
   - To overcome the *curse of dimensionality*, we note that net benefits from joining the climate club rise with the number of existing members.
   - We use iterative elimination of dominated strategies to shrink the outcome space

Return

---

[1] N denotes the number of countries that are not core members.

Unilaterally-Optimal Policy Formulas

Notation: $\sigma - 1$ (trade elasticity) $\quad$ υ (CO_2per dollar)

ζ (energy input demand elasticity)

$$\tau_i^* = \tilde{\delta}_i \sim \delta_i \tilde{P}_i \qquad \text{[carbon price]}$$

$$t_{ni,k}^* = \bar{t}_i + \tau_i^* \upsilon_{n,k} \qquad t_{ni,0}^* = \bar{t}_i \qquad \text{[import tax]}$$

$$1 + x_{in,k}^* = (1 + \bar{t}_i)\,\frac{\sigma_k - 1}{\sigma_k} + \tau_i^* \sum_{j \neq i} \left[\lambda_{jn,k} \upsilon_{j,k}\right] \frac{\sigma_k - 1}{\sigma_k} \qquad [\text{export subsidy } k \neq 0]$$

$$1 + x_{in,0}^* = (1 + \bar{t}_i)\,\frac{\sigma_0 - 1}{\sigma_0} + \tau_i^* \frac{1}{\sigma_0} \frac{\zeta_n}{\tilde{P}_{n,0}} \qquad [\text{export subsidy } k = 0]$$

Return

Unilaterally-Optimal Policy Formulas

Notation: $\sigma - 1$ (trade elasticity) υ (CO₂per dollar)

ζ (energy input demand elasticity)

$$\tau_i^* = \tilde{\delta}_i \sim \delta_i \tilde{P}_i$$ [carbon price]

$$t_{ni,k}^* = \bar{t}_i + \overbrace{\tau_i^* \upsilon_{n,k}}^{\text{carbon border tax}} \qquad t_{ni,0}^* = \bar{t}_i$$ [import tax]

$$1 + x_{in,k}^* = (1 + \bar{t}_i)\,\frac{\sigma_k - 1}{\sigma_k} + \tau_i^* \sum_{j \neq i} \left[\lambda_{jn,k} \upsilon_{j,k}\right] \frac{\sigma_k - 1}{\sigma_k}$$ [export subsidy $k \neq 0$]

$$1 + x_{in,0}^* = (1 + \bar{t}_i)\,\frac{\sigma_0 - 1}{\sigma_0} + \tau_i^* \frac{1}{\sigma_0} \frac{\zeta_n}{\tilde{P}_{n,0}}$$ [export subsidy $k = 0$]

Return