The network effects of carbon pricing

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Outline

Motivation

Macroeconomic costs and competitive drawbacks are prominent obstacles to the introduction of carbon pricing.

With interconnected industries (GVC), carbon pricing potentially affects:

1. emission-intensive industries
2. industries connected to high-carbon value chains

Network effects of carbon pricing:

1. Propagation of (price-induced) demand shocks
2. Recomposition of the global production network (Whalley and Wigle 1991)

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Research questions

- How does a price on carbon emissions affect the structure of GVC?
- Which sectors or countries bear the cost of GVC reconfigurations?

This paper

1. A production network approach to carbon pricing impacts
   - Multi country-sector model with price substitution (Baqaee and Farhi 2019; Devulder and Lisack 2020; Frankovic 2022; Sager 2021)
   - Network effects: price substitution vs. contagion of demand shocks
   - A GVC positioning perspective: input-output analysis tools

This paper

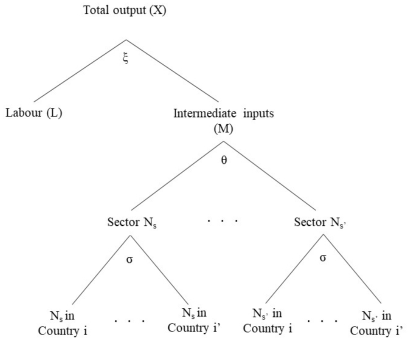
1. A production network approach to carbon pricing impacts
   - Multi country-sector model with price substitution (Baqaee and Farhi 2019; Devulder and Lisack 2020; Frankovic 2022; Sager 2021)
   - Network effects: price substitution vs. contagion of demand shocks
   - A GVC positioning perspective: input-output analysis tools
2. Results: complex network and policy interactions
   - Carbon tax shifts network centrality away from carbon-intensive countries and countries trading with them
   - Unilateral policy: increases marginalization, even with burden-sharing policies (border tax)

Outline

Model overview details

Multi-sector open-economy model with firms ($\mathcal{C} \times \mathcal{S}$) and households ($\mathcal{C}$)

- Firms: total output production with input bundle M and labor L
  $\Rightarrow$ Nested CES: elasticities ξ (labor/inputs), θ (sectors) and σ (countries)
- Households: consumption bundle C of final goods
  $\Rightarrow$ Nested CES: elasticities ρ (sectors) and ε (countries)



Introducing carbon pricing details

Carbon tax induces price and output adjustments in the economy:

- New prices: $p_{si}^{new}(\mathbf{T},\mathbf{A})$ with $\underbrace{\mathbf{T} = \left\{\tau_{si(\omega)}\right\}}_{\text{tax on direct emissions}}$ and $\underbrace{\mathbf{A} = \left\{a_{si(\omega)}\right\}}_{\text{input-output matrix}}$

- Firm-level adjustments to p^{new} in inputs:

$$a_{si}^{new} = \alpha_M \alpha_s \alpha_{si} \left(\frac{P^{new}}{P_M^{new}}\right)^{\xi} \left(\frac{P_M^{new}}{P_{Ns}^{new}}\right)^{\theta} \left(\frac{P_{Ns}^{new}}{P_{si}^{new}}\right)^{\sigma}$$

- Consumers' reaction to p^{new} in final goods:

$$G_{si}^{new} = \frac{c_{si}^{new}}{C^{new}} = \gamma_s \gamma_{si} \left(\frac{P_C^{new}}{P_{Cs}^{new}}\right)^{\rho} \left(\frac{P_{Cs}^{new}}{p_{si}^{new}}\right)^{\varepsilon}$$

Counterfactual simulations

- Data: World Input-Output Database (WIOD)
  $\Rightarrow$ 44 countries and 56 productive sectors
- Calibration:
  - Elasticities: literature in trade and production networks
    $\Rightarrow$ Atalay 2017; Baqaee and Farhi 2019
  - Techno. requirements (α) and consumption pref. (γ): WIOD
- We run 3 carbon pricing scenarios (40\$/tCO_2):
  1. global tax
  2. EU (production)
  3. EU + CBAM (production + borders)
- Revenue recycling: collected and distributed to domestic consumers

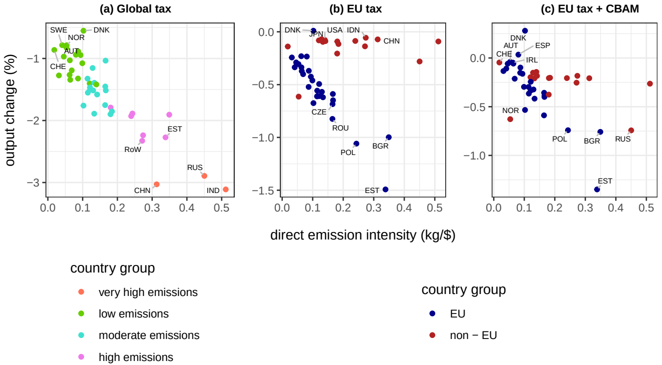
Outline

CO_2 emissions and economic impacts - world level

- Global tax vs. EU production tax vs. EU + CBAM tax:
  - Global carbon emissions: -4.5% vs. -0.3% vs. -0.4%
  - Average output change: -1.9% vs. -0.17% vs. -0.21%

Distribution of costs - country level

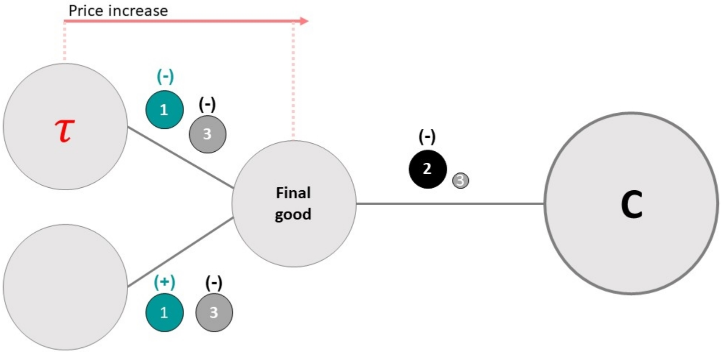
sectoral level | clustering



Network effects - drivers

What are the drivers of output loss?

1. **Input substitution** effect: direct changes in intermediate demand (firms)
2. **Direct final demand** effect: direct changes in final demand (consumers)
3. **Downstream final demand** effect: changes in intermediate demand *induced by changes in final demand*

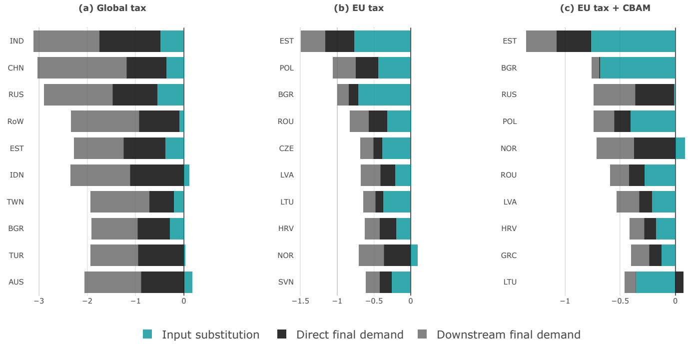


Network effects - numerical results

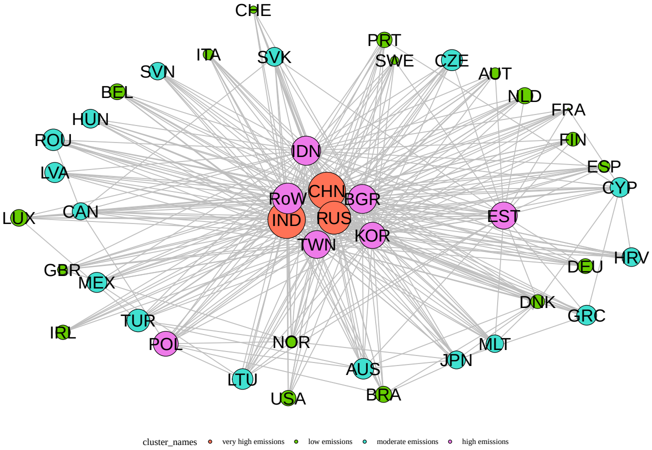
Dominant effects:

1. Global tax: demand effects
2. EU and EU+CBAM tax: input substitution responsible for most losses

⇒ Relative competitiveness losses are sharper in unilateral policy scenarios

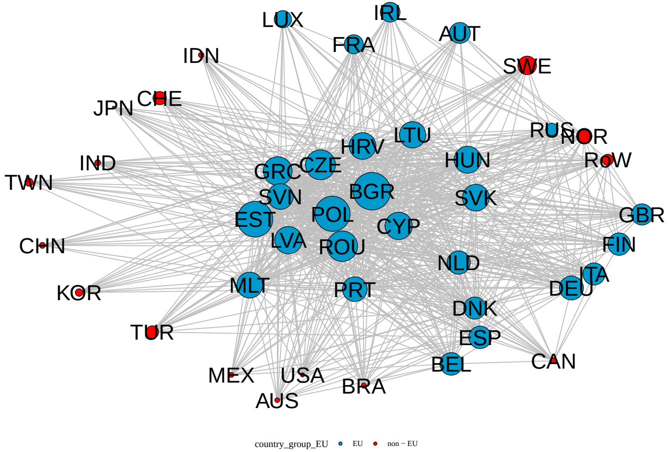


Focus: input substitution (global)



Edges: $\Delta\%$ in intermediate trade > 2; *Nodes*: $\Delta\%$ in total output

Focus: input substitution (EU+CBAM)

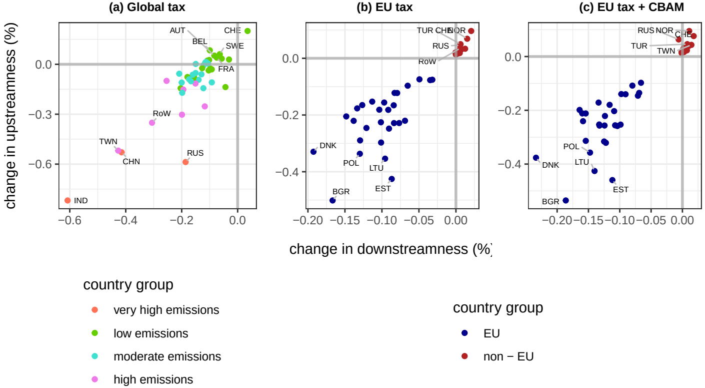


Edges: $\Delta\%$ in intermediate trade > 0.7; *Nodes*: $\Delta\%$ in total output

Network effects - GVC recomposition

A closer look at GVC positions (downstreamness/upstreamness): details

- Highly-emitting countries and connected countries: marginalization
- Unilateral EU tax shifts network towards non-EU countries (scen. 2&3)
- Adding CBAM doesn't help EU GVC marginalisation



Conclusions

1. Carbon pricing: potential cascades of price changes and output loss
   - Both direct and indirect (imported) emissions matter
   - Firms and households substitute away from carbon-intensive inputs
2. Macroeconomic impacts - winners and losers
   - GVC positioning and policy shape network effects
   - Carbon pricing reconfigures GVC
3. Coming work: policy!
   - Can a policy-maker counter GVC marginalization?
   - Recycling policies are key for welfare/competitiveness
   - Endogenizing policy: 'cascades' of policy decisions

Thank you!

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Support slides

Output and emissions changes are increasing with elasticity parameters

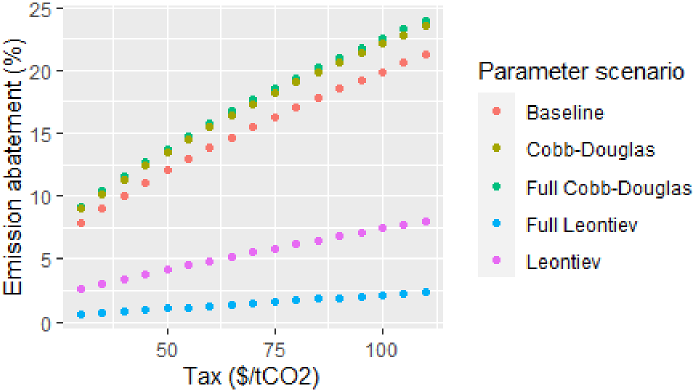
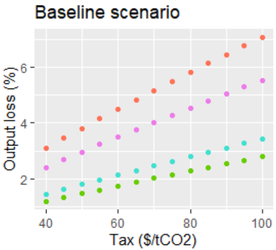


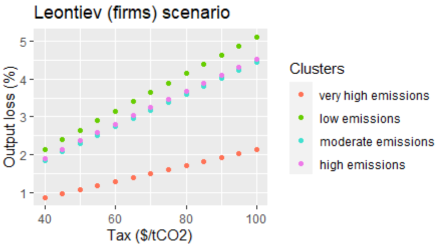
Figure: Sensivity analysis: tax range and parameter space

Sensitivity - elasticity parameters (2/2)

Winners and losers are parameter-dependent clustering

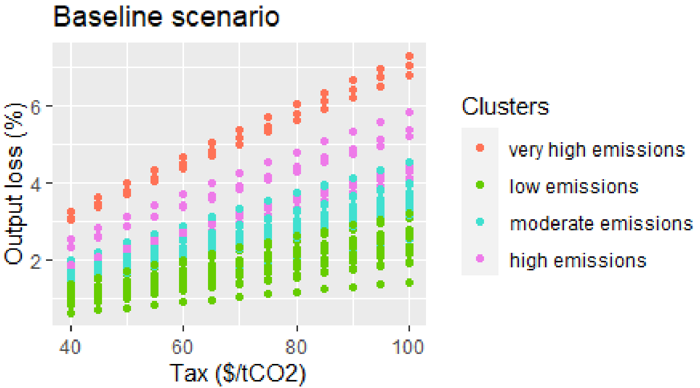
- Increased rigidity in the input market: higher price increase contagion
- Hypothesis: less emitting countries are closer to final demand
  $\Rightarrow$ Downstream price progagation + no substitution $\uparrow$ negative demand effects





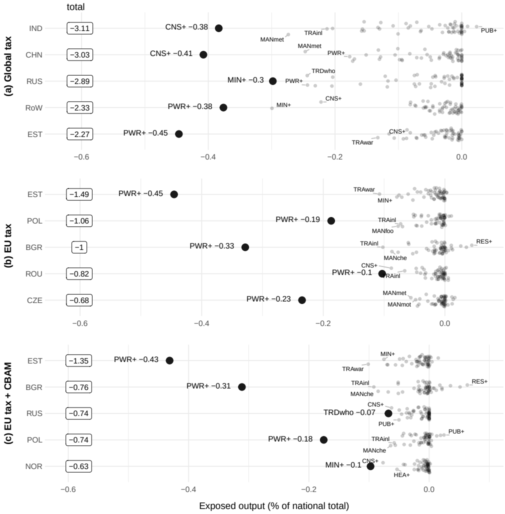
Sensitivity - tax range

- Absence of strong non-linear effects in increasing tax rate
- Increased variance in economic costs!



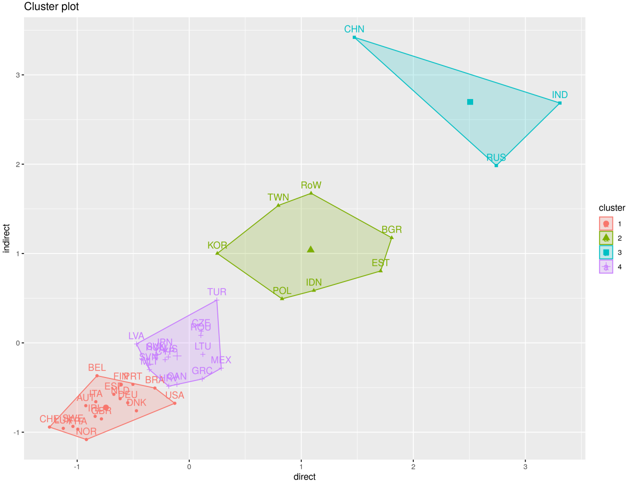
Next steps: does this translate into network statistics (centrality, degree, etc.)?

Sectoral distribution of costs back



Emission-based clustering back

- Direct emissions: own emission intensity
- Indirect emissions: emissions intensity implied by the value chain



GVC position indices back

Upstreamness - *total forward linkages*

- Average 'distance' from final use (Antràs et al. 2012; Miller and Temurshoev 2017)

$$u_i = 1 \cdot c_i + 2 \cdot \sum_j \alpha_{ij} c_j + 3 \cdot \sum_{j,k} \alpha_{ik} \alpha_{kj} c_j + 4 \cdot \sum_{j,k,l} \alpha_{il} \alpha_{lk} \alpha_{kj} c_j + \cdots .$$

Downstreamness - *total backward linkages*

- Average 'distance' from primary inputs (labor) (Miller and Temurshoev 2017)
- Average number of production stages (Fally 2012)

$$d_i = 1 \cdot \kappa_i + 2 \cdot \sum_j \alpha_{ij} \kappa_j + 3 \cdot \sum_{j,k} \alpha_{ik} \alpha_{kj} \kappa_j + 4 \cdot \sum_{j,k,l} \alpha_{il} \alpha_{lk} \alpha_{kj} \kappa_j + \cdots .$$

Notation: c_i final goods, κ_i value-added (labor), α technical coefficients.

Baseline model - Firms

- Economy populated with $\mathcal{C} \times \mathcal{S}$ representative firms
- Firms produce with a set of factors F and a bundle of intermediate inputs M, using technology

$$X = \left(\alpha_L^{\frac{1}{\xi}} L^{\frac{\xi-1}{\xi}} + \alpha_M^{\frac{1}{\xi}} M^{\frac{\xi-1}{\xi}} \right)^{\frac{\xi}{\xi-1}} \tag{1}$$

- Interm. input bundle (double-nested CES) jointly defined by

$$M = \underbrace{\left(\sum_s \alpha_s^{\frac{1}{\theta}} N_s^{\frac{\theta-1}{\theta}} \right)^{\frac{\theta}{\theta-1}}}_{\text{sectors}}, \quad N_s = \underbrace{\left(\sum_i \alpha_{si}^{\frac{1}{\sigma_s}} f_{si}^{\frac{\sigma_s-1}{\sigma_s}} \right)^{\frac{\sigma_s}{\sigma_s-1}}}_{\text{countries}}$$

- Firms minimise output costs $\Gamma = wL + \sum_{s,i} p_{si} f_{si}$

- Economy populated with $\mathcal{C}$ representative households
- Households consume a bundle of final goods C defined by

$$C = \underbrace{\left(\sum_{s \in \mathcal{S}} \gamma_s^{\frac{1}{\rho}} C_s^{\frac{\rho-1}{\rho}} \right)^{\frac{\rho}{\rho-1}}}_{\text{sectors}}, \quad C_s = \underbrace{\left(\sum_{i \in \mathcal{C}} \gamma_{si}^{\frac{1}{\varepsilon_s}} c_{si}^{\frac{\varepsilon_s - 1}{\varepsilon_s}} \right)^{\frac{\varepsilon_s}{\varepsilon_s - 1}}}_{\text{countries}}$$

- Budget constraint is

$$P_C C = w \sum_s L_s + T$$

where revenues are generated from:

- Supplying labour L at rate w
- Receiving lump-sum taxes T from carbon pricing

Baseline model - Input-output structure back

- Optimal consumption of input and final goods $\{s, i\} \in \mathcal{S} \times \mathcal{C}$ yields a linear relationship between input and output[1]

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{c}$$

  where:
  - $\mathbf{x}$ is the vector of country-sector output
  - $\mathbf{c}$ is the vector of final demand
  - $\mathbf{A}$ is the matrix of technical coefficients
- Important: both $\mathbf{A}$ and $\mathbf{c}$ are *price-dependent*
- We normalise prices to 1 to keep the model in real terms

[1] The 'Leontiev inverse' can be decomposed as a power series, such that $(\mathbf{I} - \mathbf{A})^{-1} = \mathbf{I} + \mathbf{A} + \mathbf{A}^2 + ...$; this is the basis for the decomposition of the stranding cascades hereafter.

Carbon pricing back

- Emissions δ_{si} are taxed by country-sector ω at rate $\tau_{si(\omega)}$
- Given the intermediate input market structure **A**, the new price of input $\{s, i\}$ for other firms should encompass:
  - (i) *direct* emission costs: $\delta_{si}\tau_{si(\omega)}$
  - (ii) *indirect* emission costs resulting from buying inputs further up the supply chain
- New intermediate input prices are therefore given by[2]:

$$p^{new}_{si(\omega)} = \underbrace{1}_{\text{normalised price}} + \underbrace{\delta_{si}\tau_{si(\omega)}}_{\text{direct emissions}} + \underbrace{\sum_j \sum_k \tau_{j(k)} a_{j(k)} l_{k(si)} \delta_j}_{\text{indirect emissions}}$$

[2] All $\{s, i\}, \omega, j, k \in \mathcal{S} \times \mathcal{C}$

New prices distort the *structure of the intermediate inputs market*

- $\mathbf{A}^{new}$ with elements

$$a_{si}^{new} = \alpha_M \alpha_s \alpha_{si} \left(\frac{P^{new}}{P_M^{new}} \right)^{\xi} \left(\frac{P_M^{new}}{P_{Ns}^{new}} \right)^{\theta} \left(\frac{P_{Ns}^{new}}{P_{si}^{new}} \right)^{\sigma}$$

- Price indices P_M^{new} and P_{Ns}^{new} contain a weighted average of input prices w.r.t. sectors and countries
- a_{si}^{new} coefficients are *deflated* from new prices

New equilibrium (2/3)

New prices affect *households consumption patterns*

- New share allocated to good c_{si} by country n is given by

$$\frac{c_{si}^{new}}{C^{new}} = \gamma_s \gamma_{si} \left(\frac{P_C^{new}}{P_{Cs}^{new}} \right)^{\rho} \left(\frac{P_{Cs}^{new}}{p_{si}^{new}} \right)^{\varepsilon_s}$$

- Price indices P_C^{new} and P_{Cs}^{new} contain a weighted average of input prices w.r.t. sectors and countries

New equilibrium (3/3)

- Changes in revenues after carbon pricing is introduced:

$$P_C^{new} C^{new} = r \sum_s K_s^{new} + w \sum_s L_s^{new} + T^{new}$$

  - Tax revenues T^{new} are collected at the country level and allocated to households
  - Revenues from capital and labour rK^{new} and wL^{new} are collected by domestic households

New equilibrium output

$$\mathbf{x}^{new} = (\mathbf{I} - \mathbf{A}^{new})^{-1} \mathbf{c}^{new}$$