The network effects of carbon pricing

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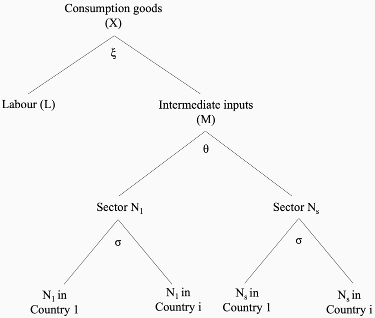
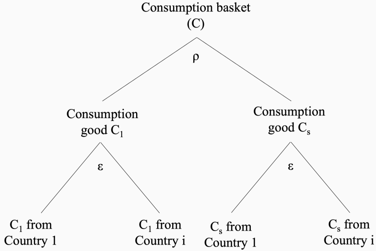
Motivation

- Climate change $\rightarrow$ Decarbonisation policies needed!
  - However: concerns over transition risks
  - Carbon pricing $\rightarrow$ macroeconomic effects and competitive drawbacks? $\rightarrow$ obstacles to implementation
- Multi-sector and multi-region perspective
  - How does transition costs propagate within the international production network?
  - Who are the winners and losers of the network reconfiguration?

Model structure

- Multi-sector open-economy model ($\mathcal{C} \times \mathcal{S}$) Details
  - Firms: nested CES production with input bundle M and labor $\rightarrow$ elasticities ξ (labor/inputs), θ (sectors) and σ (countries)
  - Consumers: nested CES consumption bundle C $\rightarrow$ elasticities ρ (sectors) and ε (countries)





Carbon pricing

- A tax on direct carbon emissions is introduced Details
  - $\rightarrow$ Cascades of price adjustments
- New equilibrium with new relative prices p, technological coefficients a and consumption shares G Details
  - New prices: $p_{si}^{new}(\mathbf{T}, \mathbf{A})$ with $\mathbf{T} = \left\{\tau_{si(\omega)}\right\}$ and $\mathbf{A} = \left\{a_{si(\omega)}\right\}$
  - Firm-level adjustments to p^{new} in inputs:

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

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

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

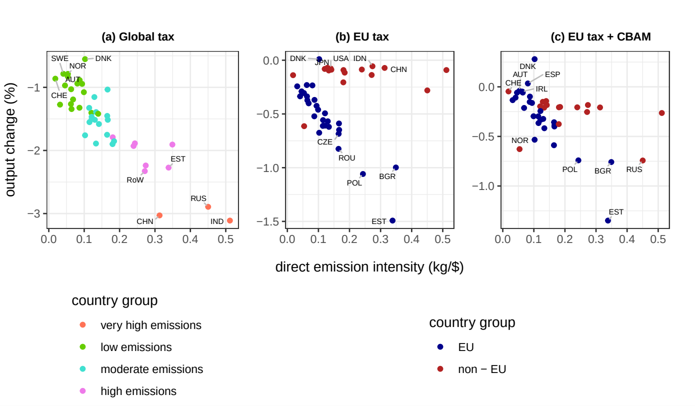
Data, calibration and scenarios

- Data: World Input-Output Database (WIOD)
  $\rightarrow$ 44 countries and 56 productive sectors
- Calibration:
  - Elasticities: literature in trade and production networks
    $\rightarrow$ Baqaee & Farhi (2020, 2021), Atalay (2017)
  - Technological requirements (α) and consumption preferences (γ): WIOD
- We run 3 carbon pricing scenarios (40\$/tCO_2):
  1. Global carbon tax
  2. EU-only carbon tax
  3. EU carbon tax + carbon border adjustment mechanism (CBAM)
- Revenue recycling: collected and distributed to domestic consumers

Results

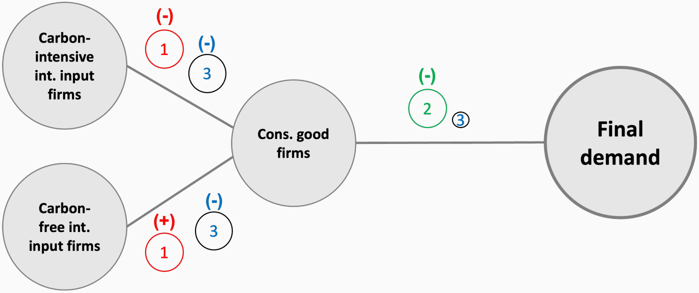
CO_2 emissions and economic impacts

- 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 costs Country clustering



Network effects - Mechanisms

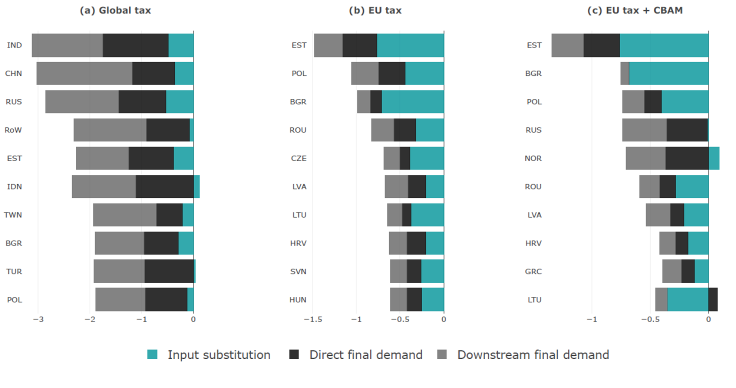
1. Input substitution:
    - Firms replace more expensive inputs with cheaper ones
2. Direct final demand:
    - Households replace more expensive consumption goods
3. Indirect final demand:
    - Final demand changes induce changes in intermediate demand



Network effects - Results

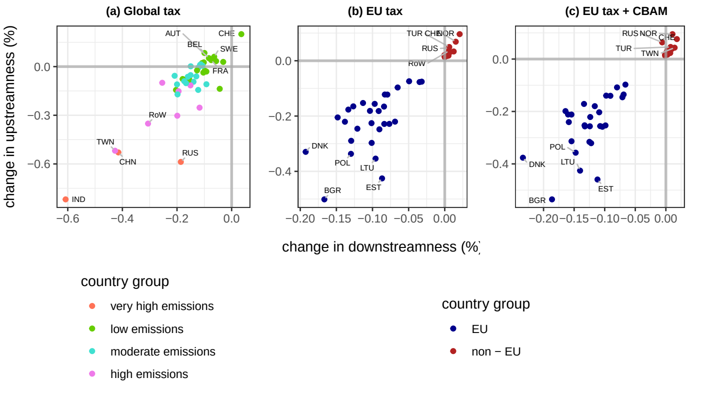
- Dominant effects:
  - Global: direct/indirect demand effects
  - EU/EU+CBAM: input substitution responsible for most losses

→ Relative competitiveness losses sharper with unilateral policies



Network recomposition

- GVC positioning (downstreamness/upstreamness) Details
  - Highly-emitting and connected countries: marginalisation
  - Unilateral EU tax shifts network towards non-EU countries
  - Adding CBAM doesn't help EU GVC marginalisation



Conclusions

Conclusions

- Carbon pricing $\rightarrow$ Potential cascades of price changes and output losses
    - Both direct and indirect (imported) emissions matter
    - Firms/households substitute away from carbon-intensive inputs
- Macroeconomic impacts - winners and losers
    - GVC positioning and policy shape network effects
    - Carbon pricing reconfigures GVC
- Coming work:
    - Technological change - fuel switching vs. process emissions
    - Revenue recycling policies key for welfare/competitiveness
    - Can a policy-maker counter GVC marginalisation?

Thank you!

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Support slides

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 $X = \min\left\{\frac{F}{\alpha_{\mathrm{F}}}, \frac{M}{\alpha_{\mathrm{M}}}\right\}$
- Factors are used in fixed proportions $F = \min\left\{\frac{K}{\alpha_{\mathrm{K}}}, \frac{L}{\alpha_{\mathrm{L}}}\right\}$
- 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 $\Gamma = \sum_{s,i} p_{si} f_{si}$

Back

Baseline model - Households

- 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

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

where revenues are generated from:

- Renting capital endowments K at rate r
- Supplying labour L at rate w
- Receiving lump-sum taxes T from carbon pricing

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Baseline model - Input-output structure

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

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

  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
- 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.

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Carbon pricing

- Emissions δ_{si} are taxed by country-sector ω at rate $\tau_{si(\omega)}$
- Given the intermediate input market structure $\mathbf{A}$, 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[1]:

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

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

New equilibrium (1/3)

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

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

$$a_{si}^{new} = a_{si} \left(\frac{P_M^{new}}{P_{Ns}^{new}} \right)^{\theta} \left(\frac{P_{Ns}^{new}}{p_{si}^{new}} \right)^{\sigma_s}$$

- 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

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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

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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

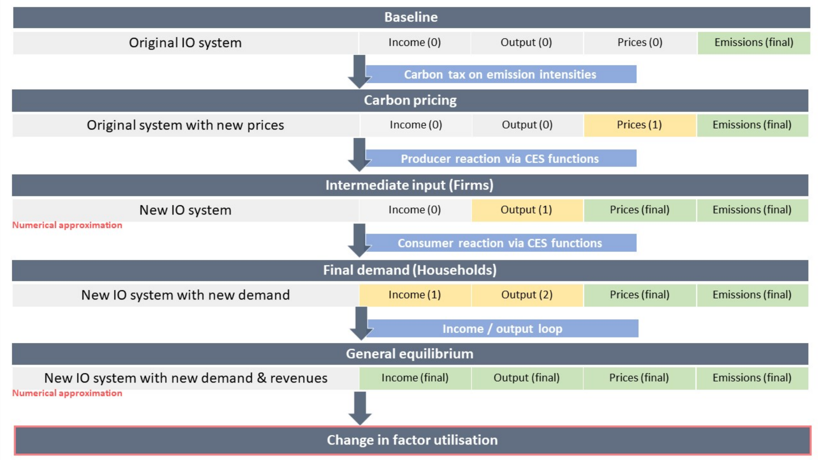
$$\mathbf{x}^{new} = (\mathbf{I} - \mathbf{A}^{new})^{-1} \mathbf{c}^{new}$$

Stranding

Defined as the change in factor utilisation

$$\Delta u = \frac{X^{new}}{X^{old}}$$

Numerical model steps



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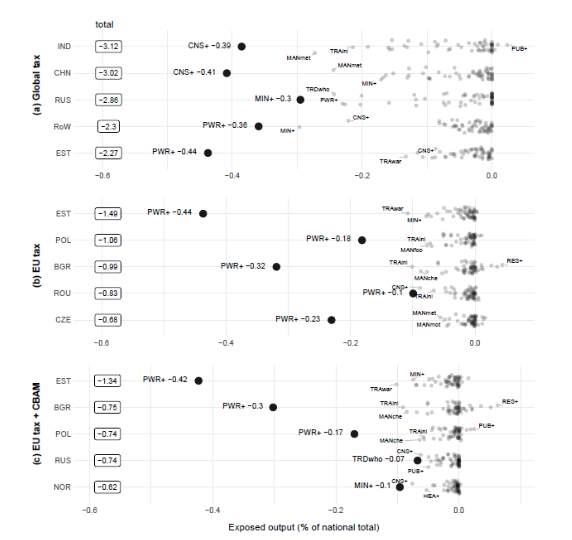
Sectoral distribution of costs



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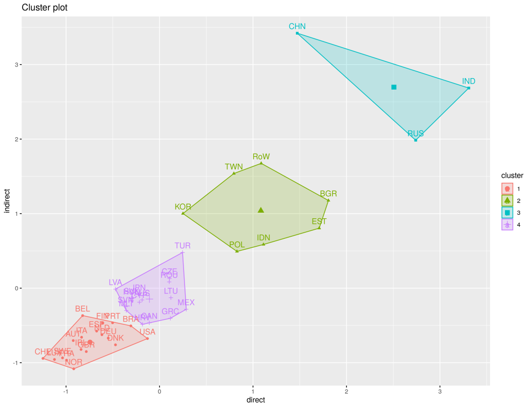
Emission-based clustering back

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



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GVC position indices back

Upstreamness - *total forward linkages*

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

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

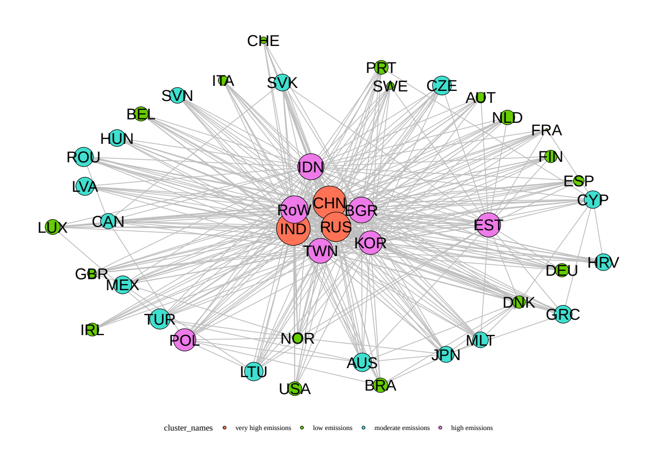
Downstreamness - *total backward linkages*

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

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

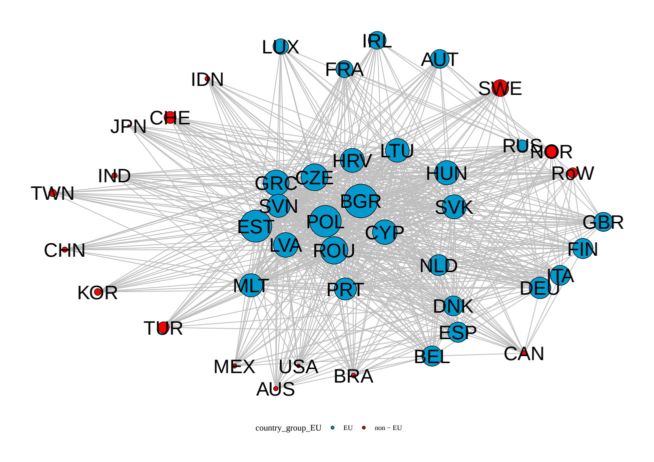
Notation: c_i final goods, κ_i value-added (labor), α technical coefficients.

Intermediate output at risk (global)



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

Intermediate output at risk (EU+CBAM)



Edges: Δ% in intermediate trade > 0.7; *Nodes*: Δ% in total output

Sensitivity - elasticity parameters (1/2)

Output and emissions changes are increasing with elasticity parameters

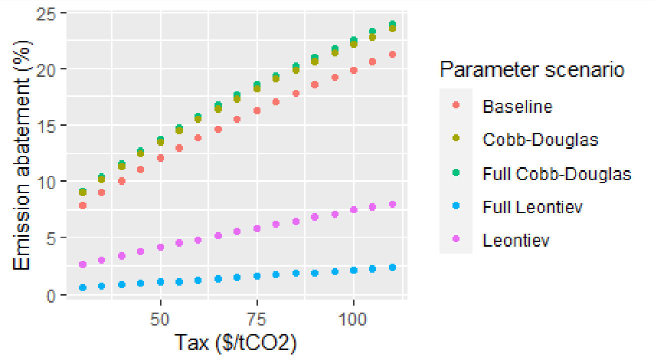
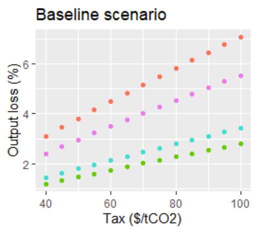


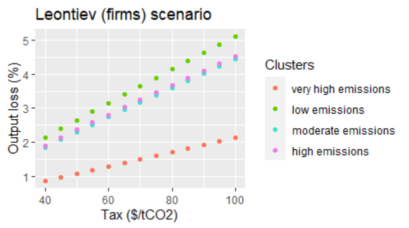
Figure: Sensivity analysis: tax range and parameter space

Sensitivity - elasticity parameters (2/2)

Winners and losers are parameter-dependent clustering

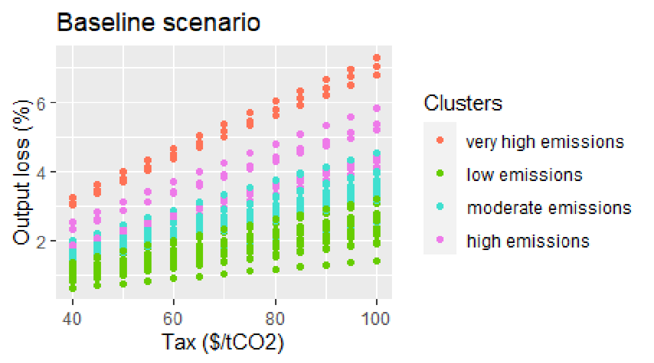
- Increased rigidity in the input market: higher price increase contagion
- Hypothesis: less emitting countries are closer to final demand $\Rightarrow$ Downstream price progagation + no substitution $\uparrow$ negative demand effects





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.)?