International Trade, Uni- and Multilateral Climate Policy, and Carbon Leakage

Mario Larch

University of Bayreuth, CEPII, CESifo, ifo Institute, GEP

mario.larch@uni-bayreuth.de

FIW-Workshop Trade and Environment
Vienna, February 20, 2018

Presentation based on:

- Larch, M. & Wanner, J., Carbon Tariffs: An Analysis of the Trade, Welfare, and Emission Effects, *Journal of International Economics*, 2017, 109, 195-213,
- Larch, M., Löning, M. & Wanner, J., Can Degrowth Overcome the Leakage Problem of Unilateral Climate Policy?, *CESifo Working Paper Series No. 6633*, 2017,

and ongoing research with Joschka Wanner.

Motivation and Contributions

Motivation

- UNFCCC efforts show the difficulty of an international solution for the reduction of CO_2 emissions.
- National and regional policies may prevail.
- Problem of carbon leakage:
  Leakage occurs if emission reductions in one country are offset by emission increases elsewhere (Felder and Rutherford, 1993).

Motivation

- So far, multilateral agreements, like Kyoto Protocol, rather ineffective (cf. e.g. Aichele and Felbermayr, 2015).
- Possible other solutions:
  - Carbon tariffs as an isolated measure,
  - Carbon tariffs accompanying other climate policy,
  - Degrowth.

What are Carbon Tariffs?

- Carbon tariffs $\neq$ Carbon taxes.
- Carbon tariffs
  - are import tariffs the level of which depends on the amount of CO_2 embodied in the traded good.
  - can be used to compensate differences in environmental regulations between two trading partners.
- Related to carbon border tax adjustment (which typically denotes a combination of import tariffs and export subsidies).
- CGE model simulations with carbon tariffs: Elliott, Foster, Kortum, Munson, Pérez Cervantes, and Weisbach (2010); Böhringer, Müller, and Schneider (2015); Böhringer, Carbone, and Rutherford (forthcoming).
- Note: structural gravity with emissions but no carbon tariffs: Aichele (2013); Egger and Nigai (2012, 2015); Shapiro and Walker (2015); Shapiro (2016).

What is Degrowth?

- Downscaling of the economy as a whole.
- Often assumed to restrict the quantity of available factor inputs (e.g. working time, natural resources and land).
- Degrowth generally argues for a broader set of social and political goals based on a deeper transformation of the social and economic system as a whole, such as reduction of poverty, full employment, the reduction of wealth and income inequality, the promotion of international cooperation, and the development of new economic indicators of human well-being (see e.g. Victor, 2008; Jackson, 2009; Dietz and O'Neill, 2013; D'Alisa, Demaria, and Kallis, 2014).

Contribution

- Extended structural gravity model including
  - a multi-factor production function (with emissions),
  - a sectoral structure (including non-tradables), and
  - non-resource consuming, revenue-generating tariffs.
- Application of this model to investigate carbon emission and leakage effects of:
  - isolated global introduction of carbon tariffs,
  - carbon tariffs as accompanying measure of a subglobal climate policy,
  - degrowth.
- Theoretical decomposition and quantification of the emission effects of carbon tariffs in scale, composition, and technique effect (following Grossman and Krueger, 1993; Copeland and Taylor, 1994).

What Do We Find?

- Counterfactual introduction of carbon tariffs leads to
  - reduced real income for most countries, the effect being stronger for (mostly poorer) countries with “dirtier” methods of production,
  - a strong shift of emissions from low to high carbon tax countries,
  - a decrease in world carbon emissions.
- Individual countries’ emission effects and the decrease in world emissions are mainly driven by composition effects.
- Carbon tariffs can strongly reduce the leakage associated with subglobal climate policies.
- Degrowth is also able to reduce carbon leakage substantially, but at rather high costs.

Model

Utility

$$U^i = \underbrace{\left(q_S^i\right)^{\gamma_S^i}}_{\text{utility from nontradable consumption}}$$

$$\times \prod_{l\in\mathcal{L}} \Bigg(\underbrace{\left[\sum_{j=1}^{N} (\beta_l^j)^{\frac{1-\sigma_l}{\sigma_l}} (q_l^{ji})^{\frac{\sigma_l-1}{\sigma_l}}\right]^{\frac{\sigma_l}{\sigma_l-1}}}_{\text{CES utility from tradable consumption}} \Bigg)^{\gamma_l^i}$$

$$\times \underbrace{\left(\frac{1}{1+\left(\frac{1}{\mu^i}\sum_{j=1}^{N} E^j\right)^2}\right)}_{\text{Disutility due to carbon emissions}} \text{, with } \gamma_S^i + \sum_{l\in\mathcal{L}} \gamma_l^i = 1.$$

- Constant expenditure shares; trade due to love of variety; almost constant social cost of carbon.

Production

- Multiple-factor Cobb-Douglas production function:

$$q_l^i = A_l^i (E_l^i)^{\alpha_{lE}^i} \prod_{f \in \mathcal{F}} (V_{lf}^i)^{\alpha_{lf}^i}, \quad \text{with} \quad \alpha_{lE}^i + \sum_{f \in \mathcal{F}} \alpha_{lf}^i = 1.$$

- Energy:
  - either exogenously fixed (real) price or fixed targeted amount,
  - completely elastic supply at the fixed price (role of OPEC as potential justification: cf. Böhringer, Rosendahl, and Schneider, 2014),
  - linear relationship with carbon emissions.
- Other factors:
  - fixed amounts V_f^i,
  - frictionless, national factor markets (i.e. $\sum_l V_{lf}^i = V_f^i$).

Income and Expenditure

- Income stems from production and tariff revenues:

$$Y^i = Y^i_S + \sum_{l \in \mathcal{L}} Y^i_l + \sum_{l \in \mathcal{L}} \sum_{j=1}^{N} (\tau^{ji}_l - 1) X^{ji}_l.$$

- Consumers spend money on local non-tradable goods and tradable goods from all countries:

$$\mathfrak{X}^i = \mathfrak{X}^i_S + \sum_{l \in \mathcal{L}} \mathfrak{X}^i_l = Y^i_S + \sum_{l \in \mathcal{L}} \sum_{j=1}^{N} X^{ji}_l.$$

- We additionally assume balanced trade, i.e. $Y^i = \mathfrak{X}^i$.

Trade Flows

Gravity

Trade flows follow a gravity equation, accounting for the sectoral structure and tariffs:

$$X_l^{ij} = \frac{\gamma_l^j Y^j Y_l^i}{Y^W} \left(\frac{T_l^{ij}}{\Pi_l^i P_l^j} \right)^{1-\sigma_l} \left(\tau_l^{ij} \right)^{-\sigma_l},$$

$$\Pi_l^i = \left[\sum_{j=1}^N \left(\frac{T_l^{ij}}{P_l^j} \right)^{1-\sigma_l} \left(\tau_l^{ij} \right)^{-\sigma_l} \gamma_l^j \theta^j \right]^{\frac{1}{1-\sigma_l}} \text{, with } \theta^j = Y^j / Y^W,$$

$$P_l^j = \left[\sum_{i=1}^N \left(\frac{T_l^{ij} \tau_l^{ij}}{\Pi_l^i} \right)^{1-\sigma_l} \theta_l^i \right]^{\frac{1}{1-\sigma_l}} \text{, with } \theta_l^i = Y_l^i / Y_l^W.$$

Solving the Counterfactuals

- Given the model structure for trade flows and production, we can obtain a system of equations involving Y_l^i, Y_S^i, e^i, σ_l, γ_l^j, γ_S^j, α_{lE}^i, α_{lf}^i, T_l^{ij} and τ_l^{ij}.
- These can all be directly obtained or calculated from the data, except for
  - σ_l: GTAP provides estimates,
  - T_l^{ij}: obtained by estimating the gravity equation,
  - τ_l^{ij}: exogeneuosly put, as it is the counterfactual.
- We can then solve for sectoral GDPs, prices, and multilateral resistance terms and calculate all other variables of interest from that.

Extension: Energy Production

- Allows for energy-market leakage.
- Cobb-Douglas production function as before:

$$q_l^i = A_l^i (E_l^i)^{\alpha_{lE}^i} \prod_{f \in \mathcal{F}} (V_{lf}^i)^{\alpha_{lf}^i}.$$

- Additionally: production structure for energy:

$$E^i = E_S^i + \sum_{l \in \mathcal{L}} E_l^i = A_E^i (R^i)^{\xi_R^i} \prod_{f \in \mathcal{F}} (V_{Ef}^i)^{\xi_f^i},$$

where R is a freely internationally tradable input resource and the E subscript denotes the energy sector which is not part of the l sectors.

Decomposition of Emission Effects

Decomposing the Emission Effect

Emissions in country *i* can be written as:

$$E^i = \frac{\alpha^i_{SE} Y^i_S + \sum_{l \in \mathcal{L}} \alpha^i_{lE} Y^i_l}{e^i} = \bar{\alpha}^i_E \frac{\tilde{Y}^i}{P^i} \left(\frac{e^i}{P^i} \right)^{-1},$$

where

- $\tilde{Y}^i \equiv Y^i_S + \sum_{l \in \mathcal{L}} Y^i_l$: total production,
- $\kappa^i_S = Y^i_S / \tilde{Y}^i$, $\kappa^i_l = Y^i_l / \tilde{Y}^i$: sectoral production shares, and
- $\bar{\alpha}^i_E \equiv \alpha^i_{SE} \kappa^i_S + \sum_{l \in \mathcal{L}} \alpha^i_{lE} \kappa^i_l$: production-share-weighted average energy cost share.

Decomposition of the Emission Effect

The change in emissions can be decomposed into three parts:

$$dE^i = \underbrace{\frac{\partial E^i}{\partial(\tilde{Y}^i/P^i)} d(\tilde{Y}^i/P^i)}_{\text{scale effect}} + \underbrace{\frac{\partial E^i}{\partial \bar{\alpha}_E^i} d\bar{\alpha}_E^i}_{\text{composition effect}} + \underbrace{\frac{\partial E^i}{\partial(e^i/P^i)} d(e^i/P^i)}_{\text{technique effect}},$$

$$\frac{\partial E^i}{\partial(\tilde{Y}^i/P^i)} = \frac{\bar{\alpha}_E^i}{e^i/P^i} > 0 \quad \text{and} \quad \frac{\partial E^i}{\partial(\tilde{Y}^i/P^i)} \frac{(\tilde{Y}^i/P^i)}{E^i} = 1,$$

$$\frac{\partial E^i}{\partial \bar{\alpha}_E^i} = \frac{\tilde{Y}^i}{e^i} > 0 \quad \text{and} \quad \frac{\partial E^i}{\partial \bar{\alpha}_E^i} \frac{\bar{\alpha}_E^i}{E^i} = 1,$$

$$\frac{\partial E^i}{\partial(e^i/P^i)} = -\frac{\bar{\alpha}_E^i \tilde{Y}^i/P^i}{(e^i/P^i)^2} < 0 \quad \text{and} \quad \frac{\partial E^i}{\partial(e^i/P^i)} \frac{(e^i/P^i)}{E^i} = -1.$$

▸ Two-sector decomposition ▸ Log-change decomposition

Data and Model Validation

Data

- Production and trade flow data: Global Trade Analysis Project (GTAP) 8 database.
  - Main data source.
  - 129 regions covering all countries in the world.
  - 57 sectors, aggregated to one nontradable and 14 tradable sectors in our work.
  - 5 factors plus energy.
- Data on regional trade agreements: Mario Larch's RTA database (Egger and Larch, 2008).
- Other gravity variables: CEPII dataset as constructed by Head, Mayer, and Ries (2010).
- Social cost of carbon: Interagency Working Group on the Social Cost of Carbon.
  - Regional distribution thereof: Nordhaus and Boyer (2000).

▸ Gravity estimation ▸ Regression results ▸ Bootstrapped standard errors

Model Validation

- (Sectoral) Output: perfectly fitted.
- National emissions: perfectly fitted.
- Sectoral emissions: very highly correlated ($\varnothing\ r = 0.96$).
- Sectoral trade flows: very good fit ($\varnothing$ Pseudo-R^2=0.86).
- Response to policy shock: We compare the leakage rates of a 20 % reduction in emissions by the Annex I countries of the Kyoto Protocol with and without carbon tariffs to the values in the survey by Böhringer, Balistreri, and Rutherford (2012):
  - No tariffs:
    - Our model: 12.5 %.
    - Literature: 5 to 19 %.
  - With tariffs:
    - Our model: 3.6 %.
    - Literature: 2 to 12 %.

Leakage rate

Counterfactuals

Counterfactuals

We consider three different counterfactuals:

- Carbon tariffs as an isolated measure,
- Carbon tariffs accompanying other climate policy,
- Degrowth.

Carbon Tariffs as an Isolated Measure

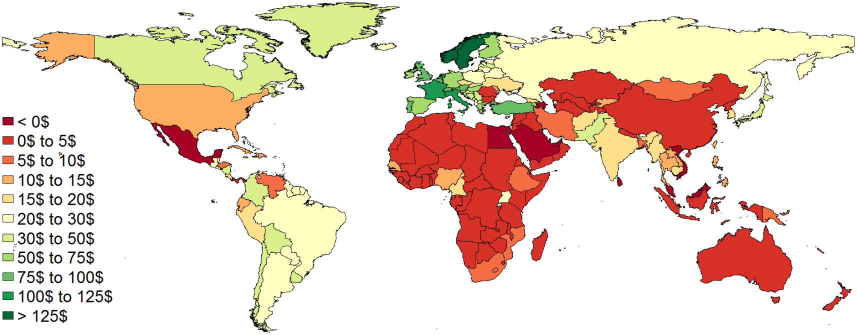
Scenario I: Carbon Tariffs as an Isolated Measure

- We can obtain implicit carbon taxes (λ^i) and sectoral emissions from the data.
- The carbon tariff is then calculated for each country pair in such a way as to compensate for the difference in carbon taxes per ton of carbon embodied in the good:

$$\tau_l^{ij} = \begin{cases} 1 + \frac{E_l^k}{Y_l^k}(\lambda^j - \lambda^i) & \text{if } \lambda^j > \lambda^i, \\ 1 & \text{if } \lambda^j \leq \lambda^i. \end{cases}$$

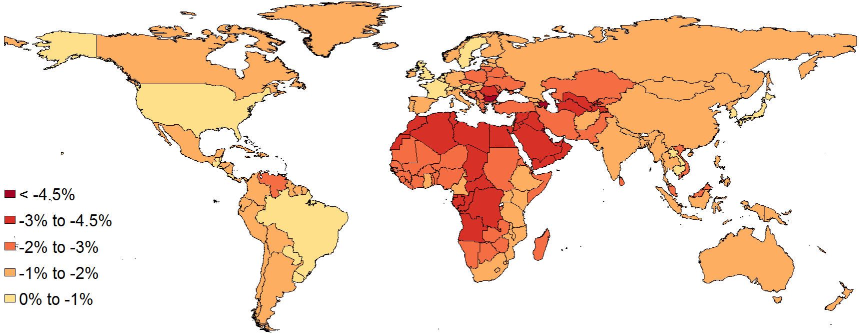
- **Product-based** ($k = j$) (or production-based ($k = i$)).
- Implication: For every ton of CO_2 embodied in a good sold in country j (assuming j's production technology is used), the sum of carbon tax and tariff paid is at least as high as the carbon tax in j.

Implicit Carbon Taxes



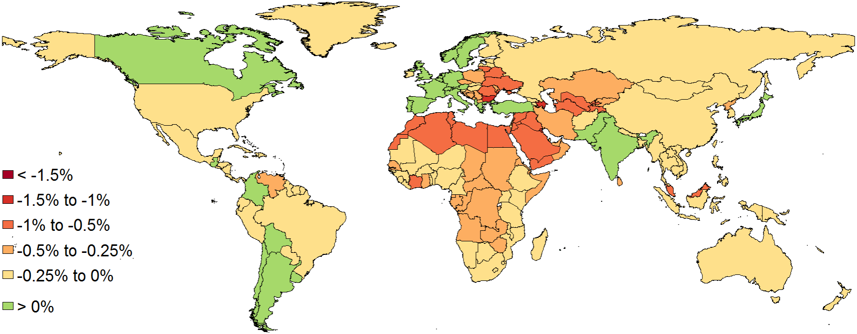
- The values range between -13 US-$ in Malaysia and 138 US-$ in Norway.

Percentage Changes in Normalized Trade Flows



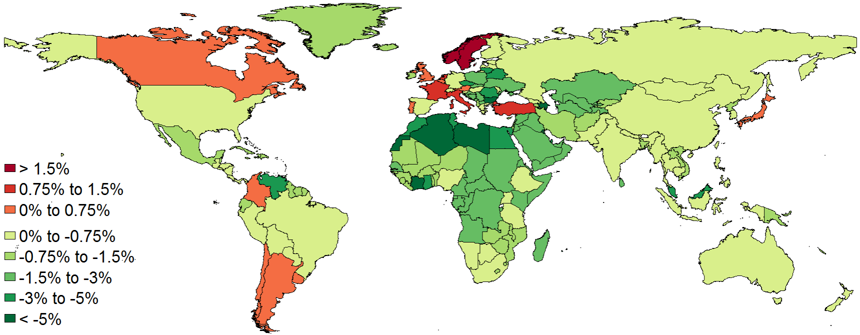
- The values range between -5.9 % for Azerbaijan and -0.66 % for Sweden.
- World trade flows go down by 1.9 %.

Percentage Changes in Welfare



- The values range between -1.5 % for Bahrain and 0.3 % for Norway.
- 79 % of all countries experience a welfare loss.

Percentage Changes in Carbon Emissions



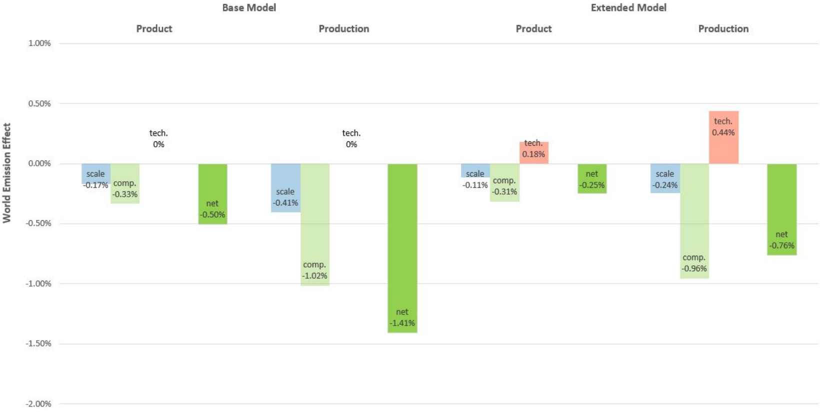
- Values between -7.0 % for Bulgaria and 2.1 % for Norway.
- World emissions decrease by 0.5 %.

Quantifying the Decomposition

- The world emission decrease approximately decomposes into
  - world scale effect: -0.17 %
  - world composition effect: -0.33 %
  - world technique effect: 0 in the base model.
- For individual countries, the composition effect accounts for 67 % of the emission change on average.

▸ Robustness checks

Base vs. Extended Model: Decomposition



Carbon Tariffs Accompanying other Climate Policy

Scenario II: Carbon Tariffs Accompanying other Climate Policy

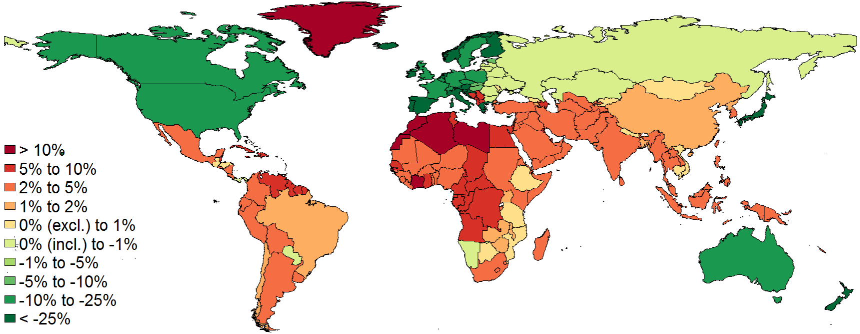
- Subglobal climate policy: Some countries commit to emission reduction targets, some do not.
- Emission reduction of committed countries will be partly offset by non-committing countries due to carbon leakage.
- Specific Scenario: Copenhagen Accord pledges of the Appendix I countries
  - without carbon tariffs,
  - with carbon tariffs.

Table: National Pledges in the Copenhagen Accord (Appendix I)

Australia	23%	Austria	38%	Belar.	0%	Belg.	23%
Bulgaria	0%	Canada	17%	Croatia	48%	Cyprus	57%
Cz. Rep.	16%	Denmark	10%	Eston.	9%	Finland	39%
France	25%	Germany	11%	Greece	43%	Hung.	7%
Ireland	48%	Italy	32%	Japan	34%	Kazak.	0%
Latvia	0%	Lithuania	0%	Luxem.	32%	Malta	40%
Netherl.	31%	New Zeal.	40%	Norway	55%	Poland	12%
Portugal	48%	R.o.EFTA	25%	Roman.	0%	Russia	0%
Slovakia	10%	Slovenia	42%	Spain	54%	Swed.	19%
Switzerl.	16%	Ukraine	0%	UK	21%	USA	17%

Appendix II pledges

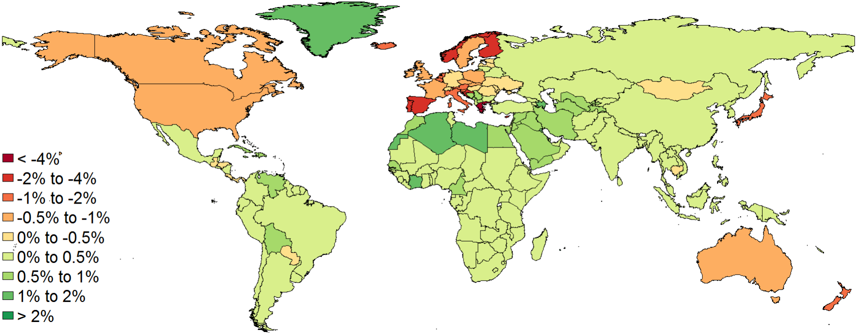
Copenhagen without Tariffs: Emission Effects



- Values between -57.4 % for Cyprus and 12.6 % for Rest of North Africa.
- World emiss. decrease by 8.4 % (leakage rate of 13.4 %).

Decomposition

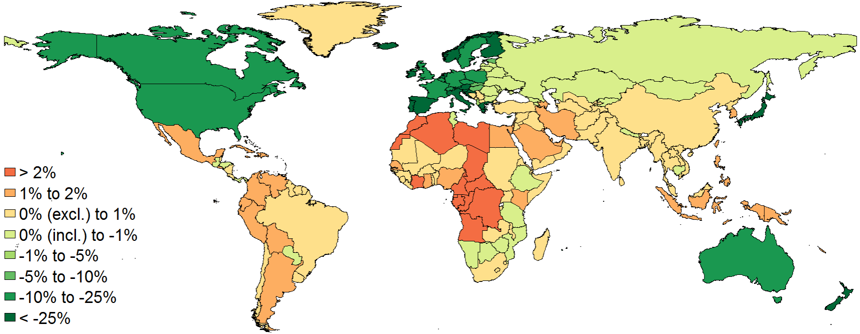
Copenhagen without Tariffs: Welfare Effects



- The values range between -4.7 % for Greece and 2.2 % for Bahrain.

Welfare vs. real income effects

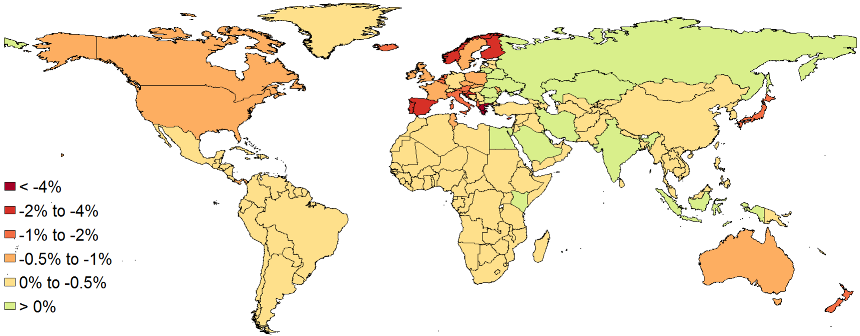
Copenhagen with Tariffs: Emission Effects



- Values between -57.4 % for Cyprus and 2.4 % for Cote d'Ivoire.
- World emiss. decrease by 9.3 % (leakage rate of 4.1 %).

Decomposition

Copenhagen with Tariffs: Welfare Effects



- The values range between -4.6 % for Greece and 0.4 % for Belarus.

▸ Results including Appendix II pledges

Degrowth

Scenario III: Degrowth

- Quantity restrictions on all available factors.
- Victor (2008), Jackson (2009), Hardt and O'Neill (2017).

The Degrowth Scenarios

The Committed Country

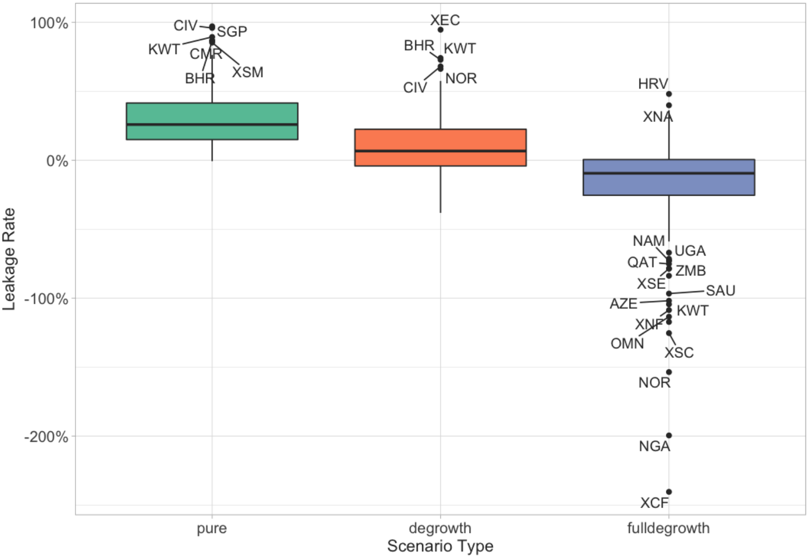
Hypothetical 10% reduction target.

1. **Pure emission target:** energy use (E^i),
2. **Simple degrowth:** energy use and other regional factors (V^i_f),
3. **Full degrowth:** energy use, regional factors and international resource supply ($\omega^i R^W$).

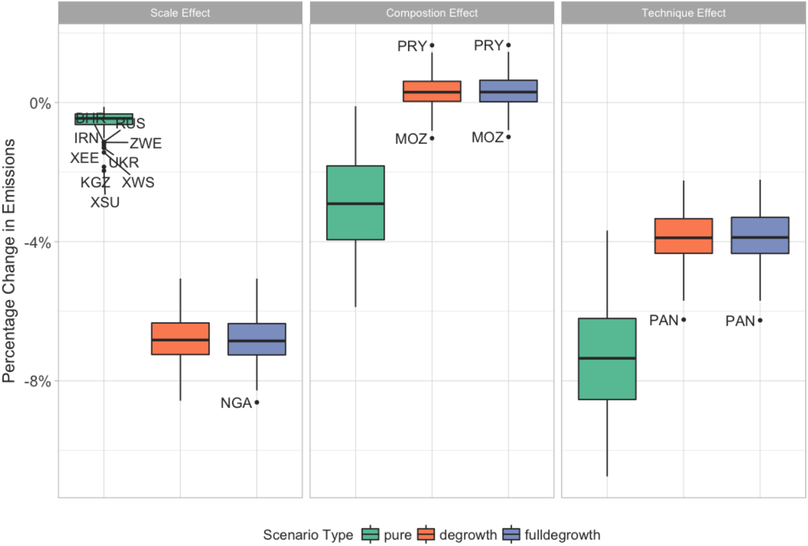
The Uncommitted Countries

Adjust endogenously to policy changes in trading partner.

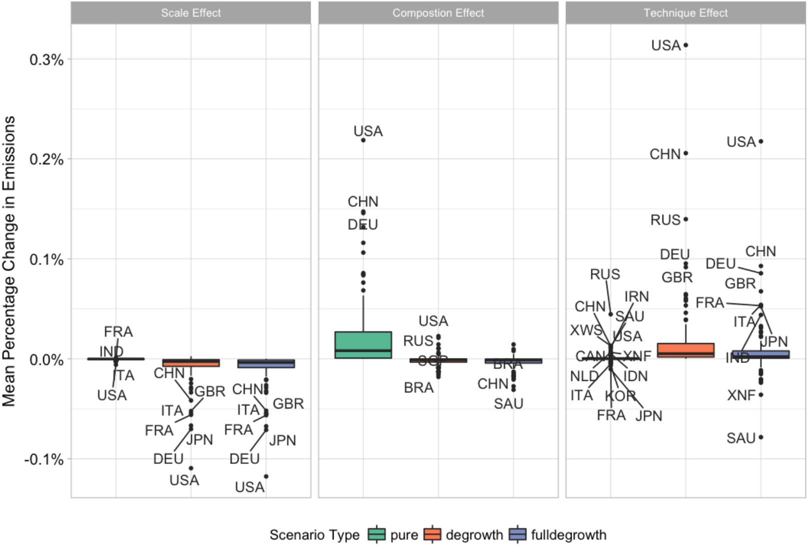
Comparing Carbon Leakage



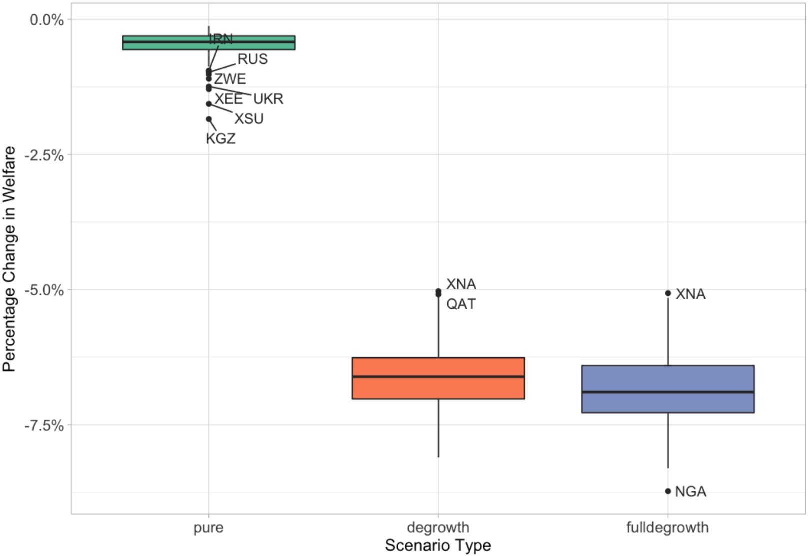
Decomposing Emission Effects (Committed Country)



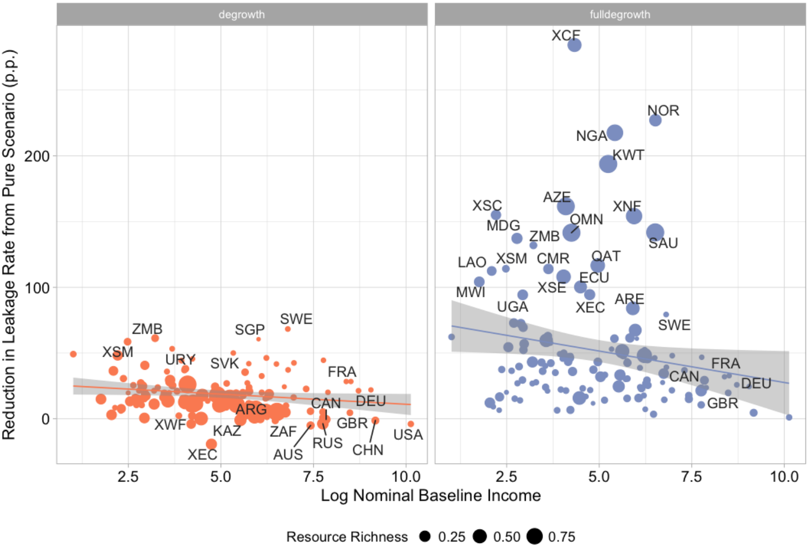
Decomposing Emission Effects (Uncommitted Country)



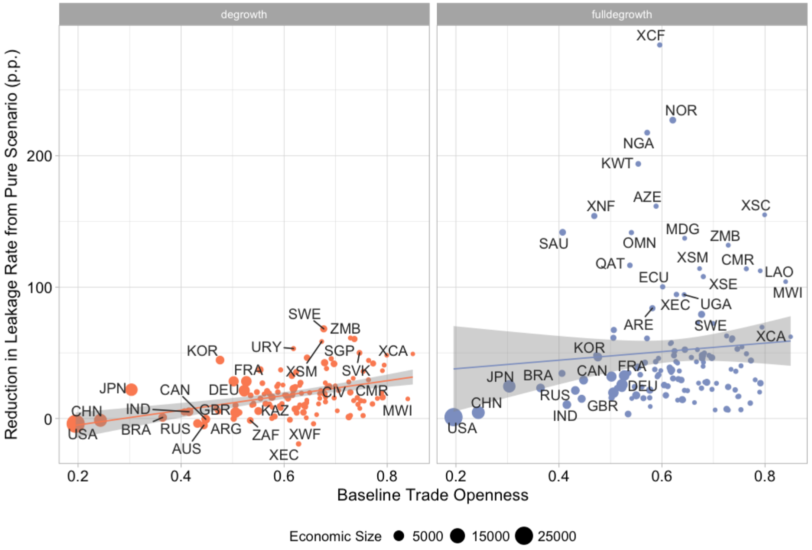
Comparing Welfare Effects (Committed Country)



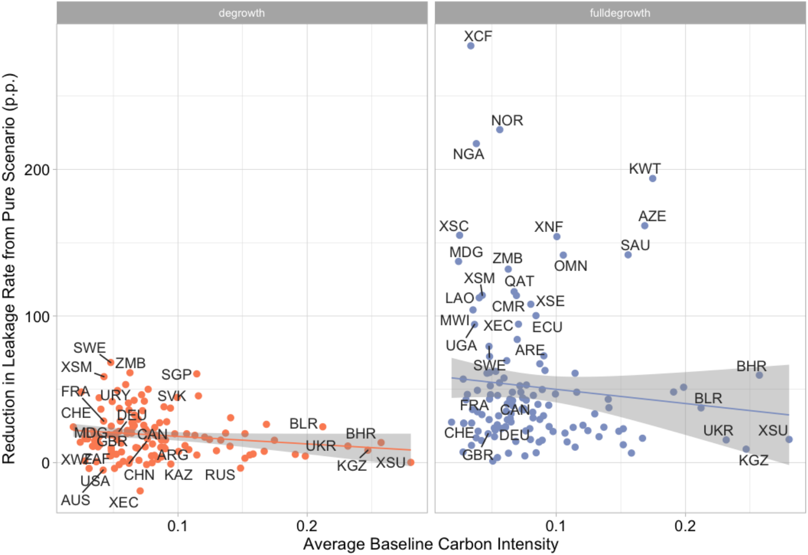
Carbon Leakage vs. Economic Size



Carbon Leakage vs. Trade Openness



Carbon Leakage vs. Average Energy Intensity



Summary of Degrowth Counterfactual

- Simple degrowth limits compositional shift towards production of dirtier products.
- Full degrowth limits shift to dirtier production techniques.
- Strong real income losses for committed countries.
- Especially effective in smaller, more trade-open and cleaner economies compared to pure emission targets.

Conclusions

Conclusions

- We build a multi-sector, multi-factor structural gravity model including tariffs.
- The counterfactual introduction of carbon tariffs leads to
  - a strong shift of carbon emissions (i.e. a reduction of carbon leakage),
  - real income losses for most countries, and
  - a decrease in world carbon emissions.
- Composition is the main driver of both national emission changes and the world emission reduction in response to carbon tariffs.
- Subglobal climate policy becomes more effective if accompanied by carbon tariffs.
- Degrowth has a strong potential to limit carbon leakage, even though at comparable high costs.

Outlook

- Further applications we are currently working on:
  - Unilateral withdrawals from the Paris Agreement.
  - Evaluate emission effects of trade liberalization.
- Potential future extensions of the model include amongst others
  - the incorporation of trade in intermediate goods,
  - an integrated assessment component for climate damages,
  - a distinction of different energy sources ("green" vs. coal vs. oil),
  - a dynamic model structure (including growth and technical change).

Thank you very much for your attention!

I am looking forward to your questions and the discussion.

References I

AICHELE, R. (2013): "Carbon Leakage with Structural Gravity," *Beiträge zur Jahrestagung des Vereins für Socialpolitik 2013: Wettbewerbspolitik und Regulierung in einer globalen Wirtschaftsordnung - Session: Climate Policy I*, A04-V3.

AICHELE, R., AND G. FELBERMAYR (2015): "Kyoto and Carbon Leakage: An Empirical Analysis of the Carbon Content of Bilateral Trade," *Review of Economics and Statistics*, 97(1), 104–115.

BÖHRINGER, C., J. C. CARBONE, AND T. F. RUTHERFORD (forthcoming): "Embodied Carbon Tariffs," *Scandinavian Journal of Economics*.

References II

Böhringer, C., E. J. Balistreri, and T. F. Rutherford (2012): "The Role of Border Carbon Adjustment in Unilateral Climate Policy: Overview of an Energy Modeling Forum Study (EMF 29)," *Energy Economics*, 34(Supplement 2), S97–S110.

Böhringer, C., A. Müller, and J. Schneider (2015): "Carbon Tariffs Revisited," *Journal of the Association of Environmental and Resource Economists*, 2(4), 629–672.

Böhringer, C., K. E. Rosendahl, and J. Schneider (2014): "Unilateral Climate Policy: Can OPEC Resolve the Leakage Problem?," *Energy Journal*, 35(4), 79–100.

Copeland, B. R., and M. S. Taylor (1994): "North-South Trade and the Environment," *Quarterly Journal of Economics*, 109(3), 755–787.

——— (2003): *Trade and the Environment. Theory and Evidence*. Princeton University Press, Princeton.

References III

D'ALISA, G., F. DEMARIA, AND G. KALLIS (2014): *Degrowth: A Vocabulary for a New Era*. Routledge, New York and London.

DIETZ, R., AND D. W. O'NEILL (2013): *Enough Is Enough: Building a Sustainable Economy in a World of Finite Resources*. Berrett-Koehler, San Francisco.

EGGER, P., AND M. LARCH (2008): "Interdependent Preferential Trade Agreement Memberships: An Empirical Analysis," *Journal of International Economics*, 76(2), 384–399.

EGGER, P., AND S. NIGAI (2012): "The Copenhagen Accord: On Required Implicit Carbon Tax Rates and Their Economic Consequences," *unpublished working paper*.

——— (2015): "Energy Demand and Trade in General Equilibrium," *Environmental and Resource Economics*, 60(2), 191–213.

References IV

ELLIOTT, J., I. FOSTER, S. KORTUM, T. MUNSON, F. PÉREZ CERVANTES, AND D. WEISBACH (2010): "Trade and Carbon Taxes," *American Economic Review: Papers and Proceedings*, 100(2), 465–469.

FELDER, S., AND T. F. RUTHERFORD (1993): "Unilateral CO_2 Reductions and Carbon Leakage: The Consequences of International Trade in Oil and Basic Materials," *Journal of Environmental Economics and Management*, 25(2), 162–176.

GROSSMAN, G. M., AND A. B. KRUEGER (1993): "Environmental Impacts of a North American Free Trade Agreement," in *The U.S.-Mexico Free Trade Agreement*, ed. by P. M. Garber, pp. 13–56. MIT Press, Cambridge, MA.

HARDT, L., AND D. W. O'NEILL (2017): "Ecological Macroeconomic Models: Assessing Current Developments," *Ecological Economics*, 134, 198–211.

References V

HEAD, K., T. MAYER, AND J. RIES (2010): “The Erosion of Colonial Trade Linkages after Independence,” *Journal of International Economics*, 81(1), 1–14.

JACKSON, T. (2009): *Prosperity Without Growth – Economics for a Finite Planet*. Routledge, London.

LARCH, M., M. LÖNING, AND J. WANNER (2017): “Can Degrowth Overcome the Leakage Problem of Unilateral Climate Policy,” *CESifo Working Paper Series No. 6633*.

LARCH, M., AND J. WANNER (2017): “Carbon Tariffs: An Analysis of the Trade, Welfare, and Emission Effects,” *Journal of International Economics*, 109, 195–213.

NORDHAUS, W. D., AND J. BOYER (2000): *Warming the World: Economic Models of Global Warming*. MIT Press, Cambridge, Massachusetts.

References VI

OECD (2016): *Effective Carbon Rates: Pricing CO_2 through Taxes and Emissions Trading Systems*. OECD Publishing, Paris.

SHAPIRO, J. S. (2016): "Trade Costs, CO2, and the Environment," *American Economic Journal: Economic Policy*, 8(4), 220–254.

SHAPIRO, J. S., AND R. WALKER (2015): "Why is Pollution from U.S. Manufacturing Declining? The Roles of Trade, Regulation, Productivity, and Preferences," *unpublished working paper*.

VICTOR, P. A. (2008): *Managing Without Growth – Slower by Design, Not by Disaster*. Edward Elgar, Cheltenham.

Appendix

Decomposing the Emission Effect: Two Sectors

Decomposing the Emission Effect: Two Sectors

- Emissions in country i are given by:

$$E^i = \left(\alpha^i_{CE}(1-\kappa^i_D) + \alpha^i_{DE}\kappa^i_D\right)\frac{\tilde{Y}^i}{P^i}\left(\frac{e^i}{P^i}\right)^{-1},$$

where $\tilde{Y}^i \equiv \sum_{l\in\{C,D\}} Y^i_l$ is total income without tariff revenues and $\kappa^i_D = Y^i_D/\tilde{Y}^i$ is the dirty production share.

- The change in emissions can be decomposed into three parts:

$$dE^i = \underbrace{\frac{\partial E^i}{\partial(\tilde{Y}^i/P^i)}d(\tilde{Y}^i/P^i)}_{\text{scale effect}} + \underbrace{\frac{\partial E^i}{\partial\kappa^i_D}d\kappa^i_D}_{\text{composition effect}} + \underbrace{\frac{\partial E^i}{\partial(e^i/P^i)}d(e^i/P^i)}_{\text{technique effect}}.$$

Analytical Decomposition: Two Sectors

Scale effect. The effect of a ceteris paribus increase of a country's production on its emissions is positive and directly proportional to the rise in production:

$$\frac{\partial E^i}{\partial(\tilde{Y}^i/P^i)} = \left(\alpha^i_{CE}(1-\kappa^i_D) + \alpha^i_{DE}\kappa^i_D\right)\left(\frac{e^i}{P^i}\right)^{-1} > 0$$

$$\text{and} \quad \frac{\partial E^i}{\partial(\tilde{Y}^i/P^i)}\frac{(\tilde{Y}^i/P^i)}{E^i} = 1.$$

Analytical Decomposition: Two Sectors

Composition effect. The effect of an increase of the dirty production share on emissions is always positive:

$$\frac{\partial E^i}{\partial \kappa_D^i} = \left(\frac{\tilde{Y}^i}{e^i}\right)\left(\alpha_{DE}^i - \alpha_{CE}^i\right) > 0 \text{ if } \alpha_{DE}^i > \alpha_{CE}^i \;\forall\; i.$$

Analytical Decomposition: Two Sectors

Technique effect. The effect of an increase of the energy price on emissions is always negative and inversely proportional to the rise of the real energy price:

$$\frac{\partial E^i}{\partial(e^i/P^i)} = -\left(\alpha^i_{CE}(1-\kappa^i_D) + \alpha^i_{DE}\kappa^i_D\right)\frac{\tilde{Y}^i/P^i}{(e^i/P^i)^2} < 0$$

$$\text{and} \quad \frac{\partial E^i}{\partial(e^i/P^i)}\frac{(e^i/P^i)}{E^i} = -1.$$

back

Log-Change Decomposition

Log-Change Decomposition

- We additionally propose a log-change decomposition similar to Copeland and Taylor (2003) that is exact for large changes.
- Denoting changes from the baseline to the counterfactual by hats ($\hat{x} \equiv x_c / x_b$), we can write:

$$\hat{E}^i = \frac{\hat{\alpha}_E^i \widehat{\tilde{Y}^i / P^i}}{\widehat{e^i / P^i}}.$$

- Take the log and divide by the log emission change:

$$1 = \underbrace{\frac{\ln \hat{\alpha}_E^i}{\ln \hat{E}^i}}_{\text{log scale effect}} \underbrace{+ \frac{\ln \left(\widehat{\tilde{Y}^i / P^i} \right)}{\ln \hat{E}^i}}_{\text{log composition effect}} \underbrace{- \frac{\ln \left(\widehat{e^i / P^i} \right)}{\ln \hat{E}^i}}_{\text{log technique effect}} .$$

back

Estimation

Estimation

- Adding a stochastic term to the gravity equation yields:

$$X_l^{ij} = \frac{\gamma_l^j Y^j Y_l^i}{Y^W} \left(\frac{T_l^{ij}}{\Pi_l^i P_l^j} \right)^{1-\sigma_l} \left(\tau_l^{ij} \right)^{-\sigma_l} u_l^{ij}.$$

- Pooling importer and exporter specific terms, assuming $\tau_l^{ij} = 1$, and approximating trade costs as a function of observable characteristics ($T_l^{ij} = \exp((\mathbf{Z}_l^{ij})'\mathbf{b}_l)$) yields

$$X_l^{ij} = \frac{1}{Y^W} \exp\left(\left(\mathbf{Z}_l^{ij} \right)' \boldsymbol{\beta}_l \right) \mu_l^i m_l^j u_l^{ij},$$

where $\boldsymbol{\beta}_l = \mathbf{b}_l(1 - \sigma_l)$.

- This can be estimated using PPML.

▸ Regression results ▸ Bootstrapped standard errors ▸ back

Regression Results I

dep. var.	(1) $X_{agr.}$	(2) $X_{apr.}$	(3) $X_{che.}$	(4) $X_{equ.}$	(5) X_{food}	(6) $X_{mac.}$	(7) $X_{met.}$
$\ln DIST$	-1.14**	-0.93**	-0.92**	-0.60**	-0.92**	-0.77**	-0.93**
	(0.052)	(0.083)	(0.038)	(0.063)	(0.040)	(0.040)	(0.043)
RTA	0.22*	0.053	0.40**	0.87**	0.52**	0.20**	0.19*
	(0.088)	(0.11)	(0.069)	(0.099)	(0.067)	(0.071)	(0.085)
$CONT.$	0.36**	0.35**	0.17*	0.50**	0.44**	0.20**	0.51**
	(0.096)	(0.12)	(0.076)	(0.094)	(0.080)	(0.075)	(0.076)
$LANG$	0.32**	0.45**	0.024	0.084	0.29**	0.18*	0.098
	(0.11)	(0.11)	(0.093)	(0.11)	(0.083)	(0.089)	(0.098)
$COL.$	0.17	0.27$^+$	0.27*	-0.11	0.48**	0.11	0.43**
	(0.16)	(0.15)	(0.11)	(0.14)	(0.093)	(0.11)	(0.10)
$COMC.$	0.49**	-0.45*	0.20$^+$	0.47$^+$	0.74**	0.088	0.49*
	(0.16)	(0.19)	(0.12)	(0.25)	(0.14)	(0.16)	(0.21)
Obs.	16,256	16,256	16,256	16,256	16,256	16,256	16,256
Pseudo-R^2	0.776	0.962	0.901	0.936	0.849	0.906	0.846

Regression Results II

dep. var.	(8) $X_{mine.}$	(9) $X_{mini.}$	(10) $X_{oth.}$	(11) $X_{pap.}$	(12) $X_{ser.}$	(13) $X_{tex.}$	(14) X_{wood}
$\ln DIST$	-1.22**	-1.33**	-0.50**	-0.95**	-0.35**	-1.08**	-0.93**
	(0.062)	(0.11)	(0.099)	(0.046)	(0.032)	(0.052)	(0.098)
RTA	0.11	0.100	0.26	0.45**	0.14*	0.26**	0.43**
	(0.11)	(0.16)	(0.20)	(0.091)	(0.059)	(0.087)	(0.15)
$CONT.$	0.41**	0.16	0.10	0.61**	0.36**	0.10	0.71**
	(0.099)	(0.25)	(0.14)	(0.080)	(0.078)	(0.091)	(0.12)
$LANG$	0.24*	0.036	0.19	0.25**	0.14*	0.52**	0.12
	(0.11)	(0.20)	(0.14)	(0.098)	(0.060)	(0.086)	(0.13)
$COL.$	0.13	0.87**	0.24+	0.21*	0.030	0.050	0.29**
	(0.12)	(0.23)	(0.14)	(0.10)	(0.070)	(0.15)	(0.10)
$COMC.$	0.43*	0.71+	1.31**	0.72**	-0.25+	-0.54**	0.63**
	(0.20)	(0.41)	(0.29)	(0.16)	(0.15)	(0.14)	(0.15)
Obs.	16,256	16,256	16,256	16,256	16,256	16,256	16,256
Pseudo-R^2	0.769	0.641	0.929	0.920	0.886	0.894	0.849

back

Bootstrapping Standard Errors

- We want to obtain information about the precision of the results in the counterfactual scenario, taking into account the uncertainty with which we estimate trade costs.
- From estimation of the gravity equation, we obtain a point estimate $\hat{\beta}_l$, along with its variance-covariance matrix $\mathbf{\Omega}_l$.
- The results presented so far resulted from solving the model for $\hat{T}_l^{ij} = \exp(\frac{1}{1-\sigma_l}((\mathbf{Z}_l^{ij})'\hat{\beta}_l))$.
- We then additionally draw 500 times from the multivariate normal distributions $\mathcal{N}_k(\hat{\beta}_l, \mathbf{\Omega}_l)$ and solve the model for each β vector, in order to obtain confidence intervals for the counterfactual results.

back

Leakage Rate

Leakage Rate

$$LR = \left[\frac{(\sum_{i \neq pol}^{N} E_b^i + \bar{E}_c^{pol} - \sum_{i=1}^{N} E_b^i) - (\sum_{i=1}^{N} E_c^i - \sum_{i=1}^{N} E_b^i)}{(\sum_{i \neq pol}^{N} E_b^i + \bar{E}_c^{pol} - \sum_{i=1}^{N} E_b^i)} \right] \times 100$$
$$= \left[\frac{\sum_{i \neq pol}^{N} E_b^i + \bar{E}_c^{pol} - \sum_{i=1}^{N} E_c^i}{\sum_{i \neq pol}^{N} E_b^i + \bar{E}_c^{pol} - \sum_{i=1}^{N} E_b^i} \right] \times 100,$$

where $\bar{E}_c^{pol}$ is the counterfactually reduced emission level in the committed country.

- $\sum_{i \neq pol}^{N} E_b^i + \bar{E}_c^{pol} - \sum_{i=1}^{N} E_b^i$: counterfactual change of global emission without leakage, keeping the emissions of all other countries constant to the baseline.
- $\sum_{i=1}^{N} E_c^i - \sum_{i=1}^{N} E_b^i$: counterfactual change with leakage, allowing for endogenous general-equilibrium adjustments in the emission levels of all other countries.

Hence, the leakage rate measures the percentage share of the country's emission reduction that is lost globally due to emission increases elsewhere.

back

Robustness Checks

Robustness Checks

- Implicit carbon taxes:
  - Main specification: Energy taxation data from GTAP.
  - Robustness: OECD (2016) data on carbon taxation.
- Energy resource shares:
  - Main specification: Resource expenditure data from GTAP.
  - Robustness: Fossil fuel endowment data provided by the U.S. Energy Information Administration (EIA).

Robustness Checks: Results

	ΔWE	WPSE	WPCE	WPTE
Base model, product-based	-0.50	-0.17	-0.33	0
	(0.04)	(0.01)	(0.03)	
Base model, product-based	-0.38	-0.13	-0.26	0
(OECD data)	(0.03)	(0.01)	(0.02)	
Extended model, product-based	-0.25	-0.11	-0.31	0.18
	(0.02)	(0.00)	(0.03)	(0.01)
Extended model, product-based	-0.24	-0.11	-0.31	0.18
(EIA data)	(0.02)	(0.00)	(0.03)	(0.01)

back

Copenhagen Accord

Table: National Pledges Made in the Copenhagen Accord (Appendix II)

Brazil	27.8%	Chile	26.7%	China	37.1%
Costa Rica	53.4%	India	19.5%	Indonesia	13.9%
Israel	22.7%	Kyrgyzstan	18.8%	Mexico	33.2%
Singapore	6.1%	South Afr.	43.8%	South Korea	27.2%
Thailand	9.2%				

back

Copenhagen without Tariffs: Decomposition

- Committing countries' average shares:
  - Scale: 3.5 %,
  - Composition: 18.8 %,
  - Technique: 77.7 %.
- The non-committing countries' increases in emissions are overwhelmingly (∅ 88.7 %) due to compositional changes.
- World shares:
  - Scale: 2.3 %,
  - Composition: 14.3 %,
  - Technique: 83.5 %.
- The world composition effect is positive, i.e. it partially offsets the emission reduction due to changes in scale and technique.

back

Copenhagen with Tariffs: Decomposition

- Effects in the committing countries remain very similar.
- Tariffs reduce the average composition effect in the non-committing countries from a 3.4 % increase to a 1.0 % increase.
- As the committing and non-committing countries' composition effects now almost exactly cancel out, the world reduction is almost completely (94.8 %) driven by the committing countries' technique effects.

back

Welfare vs. Real Income Effects

▸ back

Copenhagen Accord Scenarios

	ΔWE	WLSE	WLCE	WLTE	LR
Appendix I, no tariffs	-8.37	0.03	-0.20	1.17	13.40
	(0.11)	(0.00)	(0.01)	(0.02)	(1.15)
Appendix I, with tariffs	-9.27	0.07	0.00	0.93	4.14
	(0.04)	(0.00)	(0.00)	(0.00)	(0.43)
Appendix I+II, no tariffs	-19.05	0.03	-0.31	1.28	6.01
	(0.08)	(0.00)	(0.02)	(0.03)	(0.41)
Appendix I+II, with tariffs	-19.98	0.08	-0.02	0.95	1.41
	(0.05)	(0.02)	(0.02)	(0.02)	(0.23)

back