Carbon Tariffs: An Analysis of the Trade, Welfare, and Emission Effects

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Motivation

- No international solution for the reduction of CO_2 emissions in sight.
- National and regional policies are likely to prevail.
- Problem of carbon leakage arises: dirty production is shifted to countries with laxer regulation.
- Possible solution: Introduction of carbon tariffs.
  - Also: potential strategic value for climate negotiations (cf. Böhringer, Carbone, and Rutherford, forthcoming)

Contribution

- Application of a state-of-the-art empirical model for the investigation of trade policies.
- We build a structural gravity model à la Anderson and van Wincoop (2003) including
  - a multi-factor production function
  - a sectoral structure (including non-tradeables), and
  - non-resource consuming, revenue-generating tariffs.
- Our simple structure allows a theoretical decomposition and quantification of the emission effects of carbon tariffs in scale, composition, and technique effect (following Copeland and Taylor, 1994).

Literature

- Carbon Tariffs: CGE models, e.g.
  - Elliott, Foster, Kortum, Munson, Perez Cervantes, and Weisbach (2010),
  - Böhringer, Carbone, and Rutherford (2011),
  - Böhringer, Bye, Faehn, and Rosendahl (2015).
- Emissions in structural gravity models:
  - Anderson and van Wincoop (2003)-type model: Aichele (2013).
  - Eaton and Kortum (2002)-type models: Egger and Nigai (2012), Egger and Nigai (2015).
- None of these papers decomposes the change in emissions into a scale, composition, and technique effect.

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What do we find?

- Counterfactual introduction of carbon tariffs leads to
  - reduced welfare (in terms of real income) for most countries, the effect being stronger for (mostly poorer) countries with “dirtier” methods of production,
  - a massive shift of emissions from high to low carbon tax countries,
  - a decrease in world carbon emissions.
- Individual countries’ emission effects are mainly driven by composition.
- The decrease in world emissions is two thirds due to the scale effect and one third due to the composition effect.

Model: Consumption

- CES utility function in tradeable sector $l \in \mathcal{L}$:

$$U_l^j = \left[\sum_{i=1}^{N} (\beta_l^i)^{\frac{1-\sigma_l}{\sigma_l}} (q_l^{ij})^{\frac{\sigma_l - 1}{\sigma_l}} \right]^{\frac{\sigma_l}{\sigma_l - 1}}, \qquad (1)$$

  and linear utility $U_S^j = q_S^j$ in the non-tradeable sector S, aggregated over sectors as $U^j = (U_S^j)^{\gamma_S^j} \prod_{l \in \mathcal{L}} (U_l^j)^{\gamma_l^j}$ with $\gamma_S^j + \sum_{l \in \mathcal{L}} \gamma_l^j = 1$.
- Budget constraint:

$$Y^j = \mathfrak{X}^j = \mathfrak{X}_S^j + \sum_{l \in \mathcal{L}} \mathfrak{X}_l^j = p_S^j q_S^j + \sum_{l \in \mathcal{L}} \sum_{i=1}^{N} p_l^{ij} q_l^{ij}. \qquad (2)$$

Model

- Denoting trade costs by T_l^{ij} and tariffs by τ_l^{ij}, we can obtain a gravity equation similar to the one by Anderson and van Wincoop (2003), but including tariffs and a sectoral structure (as e.g. in Anderson and Yotov (2010) and Caliendo and Parro (2015)):

$$X_l^{ij} = \frac{\gamma_l^j Y^j Y_l^i}{Y^W} \left(\frac{T_l^{ij}}{\Pi_l^i P_l^j} \right)^{1-\sigma_l} \left(\tau_l^{ij} \right)^{-\sigma_l}, \tag{3}$$

$$\Pi_l^i = \left[\sum_{j=1}^N \left(\frac{T_l^{ij}}{P_l^j} \right)^{1-\sigma_l} \left(\tau_l^{ij} \right)^{-\sigma_l} \gamma_l^j \theta^j \right]^{\frac{1}{1-\sigma_l}}, \text{ with } \theta^j = Y^j / Y^W, \tag{4}$$

$$P_l^j = \left[\sum_{i=1}^N \left(\frac{T_l^{ij} \tau_l^{ij}}{\Pi_l^i} \right)^{1-\sigma_l} \tilde{\theta}_l^i \right]^{\frac{1}{1-\sigma_l}}, \text{ with } \tilde{\theta}_l^i = Y_l^i / Y^W. \tag{5}$$

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Model: Production

- Two-factor Cobb-Douglas production function:

$$q_l^i = A_l^i (E_l^i)^{\alpha_{lE}^i} \prod_{f \in \mathcal{F}} (V_{lf}^i)^{\alpha_{lf}^i}, \quad \text{with} \quad \alpha_{lE}^i + \sum_{f \in \mathcal{F}} \alpha_{lf}^i = 1 \qquad (6)$$

- Energy:
  - exogeneuosly fixed price,
  - completely elastic supply at the given price (role of OPEC as potential justification: cf. Böhringer, Rosendahl, and Schneider, 2013),
  - linear relationship with carbon emissions.
- Other factors:
  - fixed amounts V_f^i,
  - frictionless factor markets (i.e. $\sum_l V_{lf}^i = V_f^i$).
- Total income: Sum of sectoral productions and tariff revenues.

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Model: Counterfactuals

- Given the model structure for trade flows and production, we can obtain a system of equations involving Y_I^i, Y_S^i, e^i, σ_I, γ_I^j, γ_S^j, α_I^i, T_I^{ij} and τ_I^{ij}.
- These can all be obtained from the data, except for
  - σ_I: put to 5,
  - T_I^{ij}: obtained by estimating the gravity equation,
  - τ_I^{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.

Estimation

- Adding a stochastic term to (3) yields:

$$X_l^{ij} = \frac{\gamma_l^j Y^j Y_l^i}{Y^W} \left(\frac{T_l^{ij}}{\Pi_l^i P_l^j} \right)^{1-\sigma_l} \left(\tau_l^{ij} \right)^{-\sigma_l} u_l^{ij}. \tag{7}$$

- 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

$$X_l^{ij} = \frac{1}{Y^W} \exp\left(\left(\mathbf{Z}_l^{ij} \right)' \beta_l \right) \mu_l^i m_l^j u_l^{ij}, \tag{8}$$

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

- This can be estimated using PPML.

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, currently aggregated to two sectors in our work.
  - All factors except energy currently aggregated to one factor.
- Data on regional trade agreements: WTO.
- Other gravity variables: CEPII (Centre d'Etudes Prospectives et d'Informations Internationales) dataset as constructed by Head, Mayer, and Ries (2010).

Regression Results

	X_C^{ij}	X_D^{ij}
ln $DISTW^{ij}$	-0.685***	-0.872***
	(0.032)	(0.039)
RTA^{ij}	0.286***	0.217***
	(0.056)	(0.073)
$CONTIG^{ij}$	0.308***	0.352***
	(0.064)	(0.068)
$COMLANG^{ij}$	0.200***	0.111
	(0.073)	(0.070)
$COLONY^{ij}$	0.054	0.236***
	(0.088)	(0.091)
$COMCOL^{ij}$	0.095	0.439***
	(0.111)	(0.163)

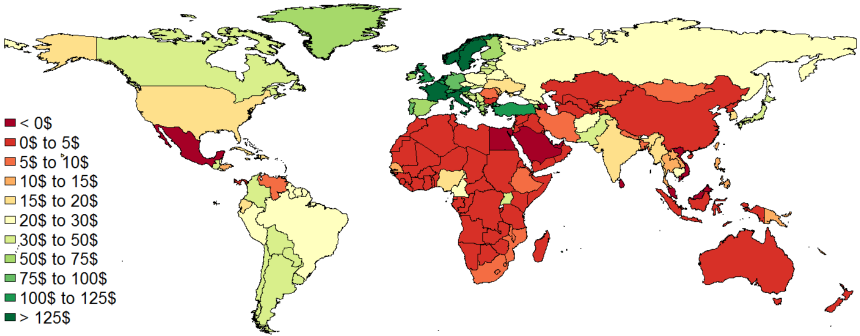
A constant, as well as importer and exporter fixed effects, were included in the regression, but are not reported here.

Counterfactual Scenario

- Introduction of carbon tariffs.
  - First evaluation in a structural gravity model.
  - First decomposition of emission effects à la Copeland and Taylor (1994).
- We can obtain implicit carbon taxes 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.

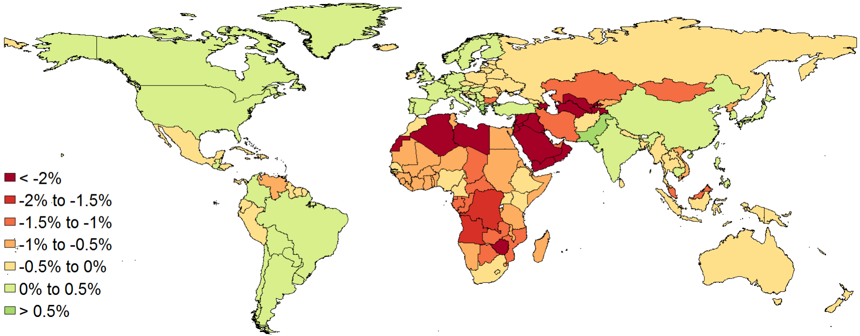
calculation

Implicit Carbon Taxes



- The values range between -14 US-$ in Malaysia and 171 US-$ in Sweden.

Percentage Changes in Real Income



- The values range between -3.82 % for Azerbaijan and 0.82 % for Greece.
- 65 % of all countries experience a welfare loss.

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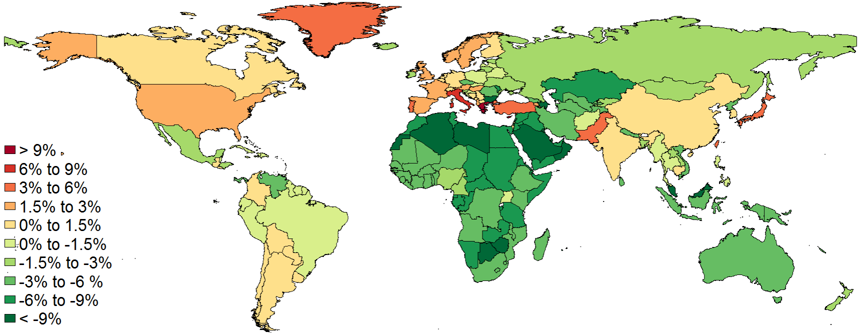
Percentage Changes in Carbon Emissions



- Values between –14.6 % for Bahrain and 12.9 % for Greece.
- World emissions decrease by 0.83 %.

Robustness check: elasticity of substitution

Decomposing the Emission Effect: Two Sectors

- Emissions in country i are given by:

$$E^i = \sum_{l \in \{C,D\}} \frac{\alpha_l^i Y_l^i}{e^i} = (1/e^i) \left(\alpha_C^i (1 - \kappa_D^i) + \alpha_D^i \kappa_D^i \right) \tilde{Y}^i,$$

  where $\tilde{Y}^i \equiv \sum_{l \in \{C,D\}} Y_l^i$ is total income without tariff revenues and $\kappa_D^i = Y_D^i / \tilde{Y}^i$ is the dirty production share.
- The change in emissions can be decomposed into three parts:

$$dE^i = \underbrace{\frac{\partial E^i}{\partial \tilde{Y}^i} d\tilde{Y}^i}_{\text{scale effect}} + \underbrace{\frac{\partial E^i}{\partial \kappa_D^i} d\kappa_D^i}_{\text{composition effect}} + \underbrace{\frac{\partial E^i}{\partial e^i} de^i}_{\text{technique effect}} .$$

Analytical Results

Decomposing the Emission Effect: Multiple Sectors

- Emissions in country i are given by:

$$E^i = \frac{\alpha^i_{SE} Y^i_S + \sum_{l \in \mathcal{L}} \alpha^i_l Y^i_l}{e^i} = \frac{\bar{\alpha}^i_E \tilde{Y}^i}{e^i}$$

where $\tilde{Y}^i \equiv Y^i_S + \sum_{l \in \mathcal{L}} Y^i_l$, $\kappa^i_S = Y^i_S / \tilde{Y}^i$, $\kappa^i_l = Y^i_l / \tilde{Y}^i$, and $\bar{\alpha}^i_E \equiv \alpha^i_{SE} \kappa^i_S + \sum_{l \in \mathcal{L}} \alpha^i_{lE} \kappa^i_l$ is the production-share-weighted average energy intensity.

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

$$dE^i = \underbrace{\frac{\partial E^i}{\partial \tilde{Y}^i} d\tilde{Y}^i}_{\text{scale effect}} + \underbrace{\frac{\partial E^i}{\partial \bar{\alpha}^i_E} d\bar{\alpha}^i_E}_{\text{composition effect}} + \underbrace{\frac{\partial E^i}{\partial e^i} de^i}_{\text{technique effect}} .$$

Analytical Results

Quantifying the Decomposition

- The world emission decrease approximately decomposes into
  - world scale effect: -0.58 %
  - world composition effect: -0.28 %
  - world technique effect: 0 in the base model.
- For individual countries, the composition effect accounts for 73 % of the emission change on average.
- Welfare effects are almost perfectly correlated with national scale effects.

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 (8), 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.
- The reduction of world carbon emission is significant (95 % confidence interval [-0.92, -0.80]).

Extended Model

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

$$q_l^i = A^i (E_l^i)^{\alpha_l^i} (L_l^i)^{1-\alpha_l^i}$$

- Additionally: production structure for energy:

$$E^i = \sum_l E_l^i = (L_E^i)^{\xi^i} (R^i)^{1-\xi^i}, \tag{9}$$

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.

Results in the Extended Model

- Generally, the results are qualitatively similar as in the base model.
- The decrease in world emissions is smaller: -0.30 %.
- Due to a decrease in the world resource price, the *world technique effect* is 0.50 %.
- Carbon leakage again is reduced and welfare effects for countries with low carbon taxes tend to be negative.

Conclusion

- We build a multi-sector, multi-factor structural gravity model including tariffs.
- The counterfactual introduction of carbon tariffs leads to
  - a massive shift of carbon emissions (i.e. a reduction of carbon leakage),
  - welfare losses for most countries, and
  - a decrease in world carbon emissions.
- The decrease in world emissions is two thirds due to a negative scale effect and one third due to the composition effect.

Conclusion

Thanks for your attention!

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Calculation of the Carbon Tariffs

- Denote the national implicit carbon tax by λ_i and the sectoral emissions by EM_l^i.
- Then, τ_l^{ij} is calculated as follows:

$$\tau_l^{ij} = \begin{cases} 1 + \frac{EM_l^j}{Y_l^j}(\lambda^j - \lambda^i) & \text{if } \lambda^j > \lambda^i, \\ 1 & \text{if } \lambda^j \leq \lambda^i. \end{cases} \tag{10}$$

- 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.

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Robustness Check: Varying the Elasticisty of Substitution

- σ_I is the only parameter not taken from the data.
- The qualitative results hold up for different values of σ_I (8 and 10).
- Concerning world emissions, even the quantitative results are very similar:
  - $\sigma_I = 8$: 0.855 % decrease (95% c.i. [-0.97, -0.80])
  - $\sigma_I = 10$: 0.860 % decrease (95% c.i. [-0.99, -0.80])

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Analytical Decomposition: Two Sectors

- Scale effect:

$$\frac{\partial E^i}{\partial \tilde{Y}^i} = (1/e^i)\left(\alpha^i_{CE}(1-\kappa^i_D) + \alpha^i_{DE}\kappa^i_D\right) > 0 \text{ and } \frac{\partial E^i}{\partial \tilde{Y}^i}\frac{\tilde{Y}^i}{E^i} = 1. \tag{11}$$

- Composition effect:

$$\frac{\partial E^i}{\partial \kappa^i_D} = \left(\tilde{Y}^i/e^i\right)\left(\alpha^i_{DE} - \alpha^i_{CE}\right) > 0 \text{ if } \alpha^i_{DE} > \alpha^i_{CE}\ \forall\, i. \tag{12}$$

- Technique effect:

$$\frac{\partial E^i}{\partial e^i} = -\left(\alpha^i_{CE}(1-\kappa^i_D) + \alpha^i_{DE}\kappa^i_D\right)\tilde{Y}^i/(e^i)^2 < 0. \tag{13}$$

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Analytical Decomposition: Multiple Sectors

- Scale effect:

$$\frac{\partial E^i}{\partial \tilde{Y}^i} = \bar{\alpha}^i_E / e^i > 0 \text{ and } \frac{\partial E^i}{\partial \tilde{Y}^i}\frac{\tilde{Y}^i}{E^i} = 1. \tag{14}$$

- Composition effect:

$$\frac{\partial E^i}{\partial \bar{\alpha}^i_E} = \tilde{Y}^i / e^i > 0 \text{ and } \frac{\partial E^i}{\partial \bar{\alpha}^i_E}\frac{\bar{\alpha}^i_E}{E^i} = 1. \tag{15}$$

- Technique effect:

$$\frac{\partial E^i}{\partial e^i} = -\bar{\alpha}^i_E \tilde{Y}^i / (e^i)^2 < 0. \tag{16}$$

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