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Industrial Structure and the Extensive Margin of Carbon Leakage Effects

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Motivation

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- Greenhouse gas emissions — climate change and global warming
- The Kyoto Protocol: common but differentiated responsibilities.
  - binding targets for industrialized countries and the European community for reducing greenhouse gas emissions.
  - no targets for developing countries.

Motivation

- Two main concerns are:
  - Competitiveness
  - Carbon Leakage: total change in emissions outside of a control region that is due to policy changes within the region.

    Carbon Leakage Rate: total change in emissions outside of a control region / total reduction in emissions within the control region.

$$Carbon\ Leakage\ Rate = \frac{\Delta(\sum_{n \neq i} E_n)}{\Delta E_i}$$

Motivation

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- Two channels of carbon leakage
  - Reallocation of carbon intensive industries.
  - Fossil fuel markets.
- Carbon Leakage — A disincentive to international emission-cutting agreements.
- No consensus on the magnitude of carbon leakage.

Literature

- CGE models: suggest a 10% – 40% leakage rate.
  - Heterogeneity in productivity and carbon intensity.

    Aw, Chen and Roberts (2001),

    Eaton, Kortum and Kramarz (2011).

    Holladay (2010).

Research Question

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- How is the magnitude of carbon leakage influenced by the differences in carbon intensity across goods?

  A Ricardian approach:

  - Based on Eaton and Kortum (2002),
  - Heterogeneity in productivity and carbon intensity,
  - Extensive margin adjustments of bilateral trade flows.

    Hillberry and McDaniel (2003), Kehoe and Ruhl (2009), Bernard, Jensen, Redding and Schott (2009).

The Ricardian Model

- A continuum of goods indexed by $j \in [0, 1]$.
- CES utility function.
- Production combines labor, intermediate inputs and energy.

$$TC_i(j) = \frac{w_i^{\alpha} p_i^{\beta} e_i^{1-\alpha-\beta}}{z_i(j)}.$$

- Heterogeneity in productivity: Country i's productivity in producing goods j, $z_i(j)$, is independently draw from:

$$F_i(z) = \Pr[Z_i < z] = e^{-T_i z^{-\theta}}.$$

- The actual price of good j in country n:

$$p_n(j) = \min\{p_{ni}(j); i = 1, ..., N\}.$$

The Ricardian Model: Carbon Leakage

- Equilibrium
- Carbon intensity per dollar: $\frac{1-\alpha-\beta}{e_i d_{ni} z_i(j)^{\lambda}}$ $(\lambda \geq 0)$
- Carbon emissions of country i's exports to country n:

$$\begin{aligned} E_{ni} &= X_{ni} \cdot \textit{Carbon intensity per dollar} \\ &= \frac{(1-\alpha-\beta)c_i}{e_i} T_i (c_i d_{ni})^{-(\theta+\lambda+1)} \Phi^{-\frac{\lambda+\theta+1}{\theta}} \Gamma\left(1+\frac{\lambda+1}{\theta}\right). \end{aligned}$$

- Country i's total emissions $E_i = \sum_n E_{ni}$.
- Carbon Leakage Rate $= \frac{\Delta(\sum_{n \neq i} E_n)}{\Delta E_i}$.

The Armington Model: Carbon Leakage

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- Equilibrium
- The amount of carbon emissions embodied in country i's exports to country n is:

$$\begin{aligned} E_{ni} &= X_{ni} \cdot \textit{Carbon intensity per dollar} \\ &= X_{ni} \cdot \frac{(1-\alpha-\beta)}{e_i d_{ni} z_i^{\lambda}}. \end{aligned}$$

- Country i's total emissions $E_i = \sum_n E_{ni}$.
- Carbon Leakage Rate $= \dfrac{\Delta(\sum_{n \neq i} E_n)}{\Delta E_i}$.

Counterfactual Experiments

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Table: $T_1 = T_2 = 1$

		Benchmark		Counterfactual — Carbon Tax	
		Country 1	Country 2	Country 1	Country 2
Wage		1	1	1	1
Labor		0.09	0.09	0.07	0.10
Price Index		0.37	0.37	0.41	0.39
Changes in Price Index (%)				10%	7%
Expenditure		0.45	0.45	0.39	0.51
Market Share	Country 1	0.71	0.29	0.64	0.36
	Country 2	0.29	0.71	0.23	0.77
$\lambda = 0$					
Simple-average	Country 1	0.029	0.010	0.026	0.012
carbon intensity	Country 2	0.010	0.029	0.007	0.032
Carbon Emissions	Ricardian model	0.042	0.042	0.021	0.050
Carbon Emissions	Armington model	0.042	0.042	0.021	0.050
Carbon Leakage Rate	Ricardian model			34.8%	
	Armington model			34.8%	

Counterfactual Experiments

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Table: $T_1 = T_2 = 1$

		Benchmark		Counterfactual — Carbon Tax	
		Country 1	Country 2	Country 1	Country 2
$\lambda = 0$					
Carbon Leakage Rate	Ricardian model				34.8%
	Armington model				34.8%
$\lambda = 1$					
Carbon Leakage Rate	Ricardian model				40.4%
	Armington model				34.8%
$\lambda = 3$					
Carbon Leakage Rate	Ricardian model				50.1%
	Armington model				34.8%

Counterfactual Experiments

Table: $T_1 = 2, T_2 = 1$

		Benchmark		Counterfactual — Carbon Tax	
		Country 1	Country 2	Country 1	Country 2
Wage		1	1	1	1
Labor		0.13	0.04	0.12	0.05
Price Index		0.24	0.27	0.27	0.29
Changes in Price Index (%)				10%	8%
Expenditure		0.61	0.29	0.58	0.31
Market Share	Country 1	0.87	0.13	0.84	0.16
	Country 2	0.52	0.48	0.47	0.53
$\lambda = 0$					
Carbon Leakage Rate	Ricardian model			16.4%	
	Armington model			16.4%	
$\lambda = 1$					
Carbon Leakage Rate	Ricardian model			18.7%	
	Armington model			19.5%	
$\lambda = 3$					
Carbon Leakage Rate	Ricardian model			23.1%	
	Armington model			27.5%	

Counterfactual Experiments

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Table: $T_1 = 1, T_2 = 2$

		Benchmark		Counterfactual — Carbon Tax	
		Country 1	Country 2	Country 1	Country 2
Wage		1	1	1	1
Labor		0.04	0.13	0.03	0.14
Price Index		0.27	0.24	0.28	0.25
Changes in Price Index (%)				10%	6%
Expenditure		0.29	0.61	0.26	0.64
Market Share	Country 1	0.48	0.52	0.42	0.58
	Country 2	0.13	0.87	0.11	0.89
$\lambda = 0$					
Carbon Leakage Rate	Ricardian model			43.1%	
	Armington model			43.1%	
$\lambda = 1$					
Carbon Leakage Rate	Ricardian model			51.6%	
	Armington model			36.3%	
$\lambda = 3$					
Carbon Leakage Rate	Ricardian model			65.4%	
	Armington model			25.6%	

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- When one country imposes unilateral carbon policies:
  - in the Ricardian model changes in the simple average carbon intensity demonstrates the extensive margin adjustments;
  - both models produce the same benchmark value and responses of trade flows, which are all determinants of carbon leakage rates;
  - the Ricardian model can duplicate the carbon leakage rate in the Armington model if it exhibits constant carbon intensity per dollar;

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- carbon leakage rates in the Ricardian model increase with the size of disparity in carbon intensity across goods;
- relative technology level is another important determinant of carbon leakage rates;
- the Ricardian model may generate higher or lower levels of carbon leakage than the typical Armington approach, depending on the degree of heterogeneity in carbon intensity across firms and countries' relative technology levels.

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- Carbon taxes in countries with higher productivity are more efficient in terms of carbon leakage.
- This paper provides the Ricardian approach as an alternative for carbon policy research.
  - Carbon leakage rates
  - Border tariff adjustment

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Thank You.