How I got here (I)

How I got here (II)

A story of two papers:

- Syverson, Chad. 2004. "Market Structure and Productivity: A Concrete Example." Journal of Political Economy 112(6): 1181-1222.

- Donaldson, Dave. 2018. "Railroads of the Raj: Estimating the Impact of Transportation Infrastructure." American Economic Review 108(4-5): 899-934.

Trade and Environment Motivation

- Important questions
- Trade can supply powerful answers/frameworks/tools
- Fun and interesting
- Many environmental economists have background in public/IO, some in labor/devo, fewer in other fields (trade, macro, theory, metrics, law&econ, . . .)
- Goal: sketch trade-environment questions, methods, literature

Trade and Environment Motivation: Questions

- **How does/should trade policy affect the environment?**
  - How do tariffs affect climate change?
  - Does globalization cause a "race to the bottom" in environmental policy?
- **How does/should environmental policy affect trade?**
  - Can environmental policy provide a hidden form of protectionism?
  - Who pays for carbon tariffs? What are the costs and benefits?
- **How can ideas from trade provide insight to environment/energy?**
  - What are the costs and benefits of abating pollution? Distribution?
  - How important are spatial/geographic aspects of climate/water/etc.?

Trade and Environment Motivation: Insights

- **Controversy over trade policy**
  - NAFTA
  - Carbon border adjustments & U.S. climate change policy

- **Intellectual arbitrage**
  - Data (firms, tariffs, NTBs, global production/trade)
  - Research designs (trade policy, shocks in other regions, roads)
  - Perspectives (geography, productivity, heterogeneity, . . .)

- **New methods**
  - Reduced form estimates -> quantitative models
  - Melitz, Eaton-Kortum models: influential in urban, public, devo, etc.

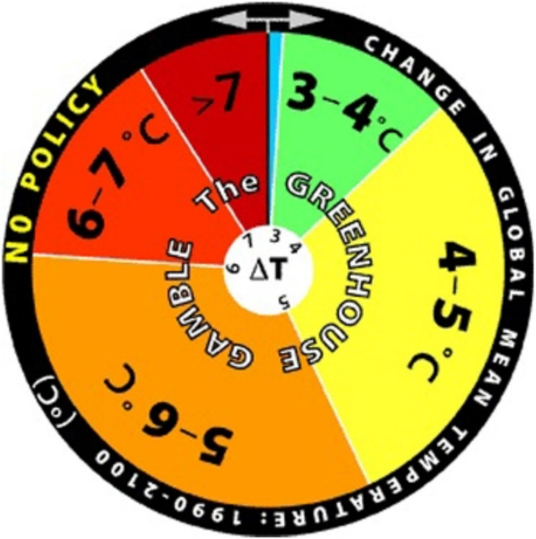
Agenda for today

- **Stylized facts in pictures**
- **Quick overview of trade/environment**
- **Toy model**
- **Paper: Trade policy and climate change**
- **Paper: Why is pollution declining?**

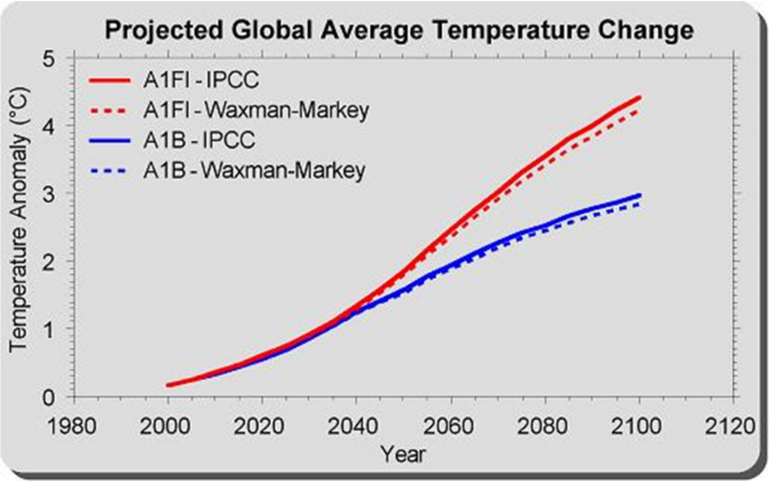
Agenda for today

- **Stylized facts in pictures**
- Quick overview of trade+environment
- Toy model
- Paper: Trade policy and climate change
- Paper: Why is pollution declining?

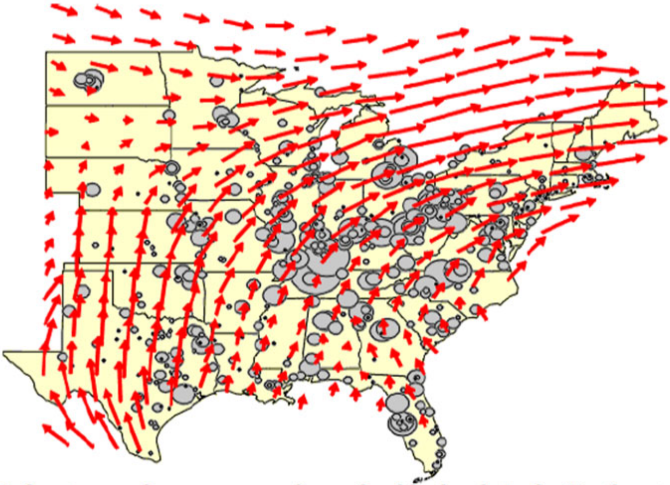
Stylized fact #1: large risks and uncertainty



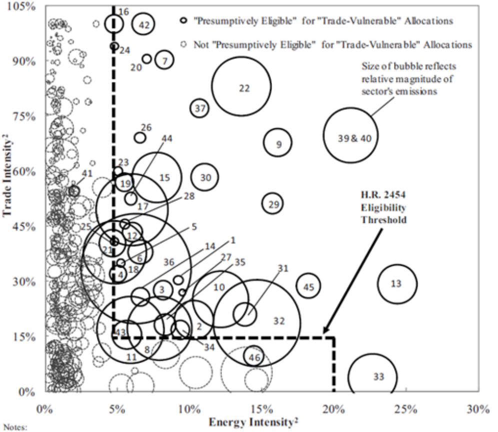
Stylized fact #2: global problems need global solutions



Stylized fact #3: environmental externalities ignore political boundaries



Stylized fact #4: Costs of environmental regulation are concentrated

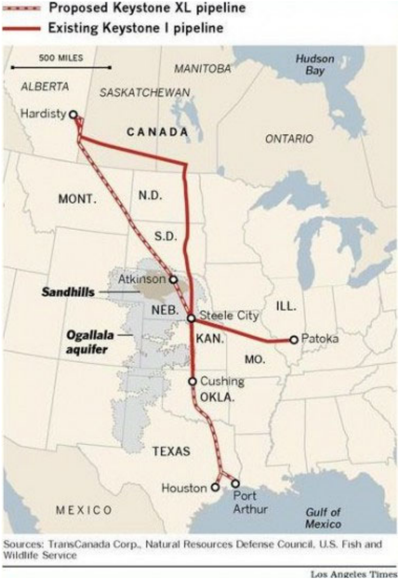


Notes:
1. Petroleum refining is not depicted because it is explicitly excluded from H.R. 2454's allocations to "trade-vulnerable" industries. Also, 91 other sectors, with 126 MMTCO$_2$e of emissions, are not depicted due to lack of trade intensity data. One of these, iron and steel pipe and tube manufacturing from purchased steel (331210; 2.5 MMTCO$_2$e) is expected to be eligible based on language in the bill. Four others meet the energy-intensity threshold, each with 2 to 3 MMTCO$_2$e of emissions: beet sugar manufacturing, broadwoven fabric finishing mills, steel foundries (except investment), and metal heat treating. Twelve sectors with a calculated trade intensity greater than 100% are depicted here with an intensity of 100% (the maximum possible intensity). The two copper sectors (212234 and 331411) do not meet the energy or trade intensity thresholds specified in H.R. 2454 but are expected to be eligible based on other language in the bill.
2. Energy intensity and trade intensity measures are as defined in H.R. 2454 and elsewhere in this report.
Source: EPA analysis.

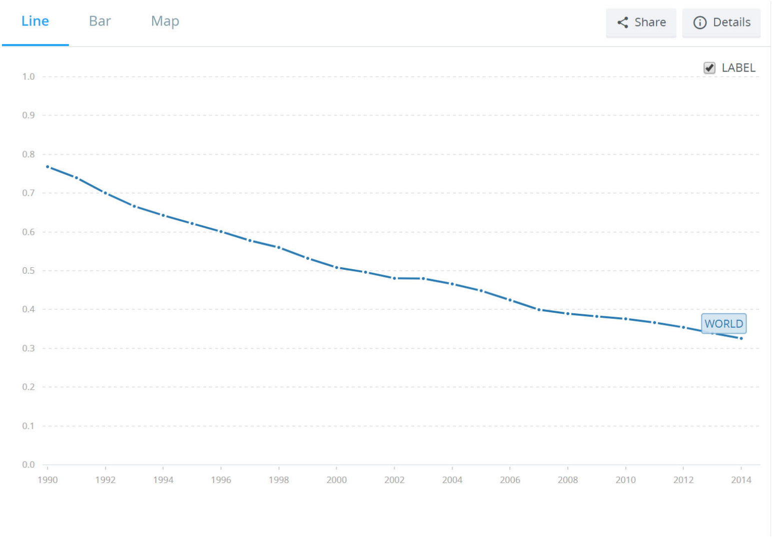
1. Malt Manufacturing (311213)
2. Wet Corn Milling (311221)
3. Rendering and Meat Byproduct Processing (311613)
4. Yarn Spinning Mills (313111)
5. Tire Cord and Tire Fabric Mills (314992)
6. Reconstituted Wood Product Manufacturing (321219)
7. Pulp Mills (322110)
8. Paper (except Newsprint) Mills (322121)
9. Newsprint Mills (322122)
10. Paperboard Mills (322130)
11. Petrochemical Manufacturing (325110)
12. Inorganic Dye and Pigment Manufacturing (325131)
13. Alkalies and Chlorine Manufacturing (325181)
14. Carbon Black Manufacturing (325182)
15. All Other Basic Inorganic Chemical Mfg. (325188)
16. Cyclic Crude and Intermediate Manufacturing (325192)
17. All Other Basic Organic Chemical Mfg. (325199)
18. Plastics Material and Resin Manufacturing (325211)
19. Synthetic Rubber Manufacturing (325212)
20. Cellulosic Organic Fiber Manufacturing (325221)
21. Noncellulosic Organic Fiber Manufacturing (325222)
22. Nitrogenous Fertilizer Manufacturing (325311)
23. Vitr. China Plumbing Fixture and Other Mfg. (327111)
24. Vitreous China and Other Pottery Mfg. (327112)
25. Porcelain Electrical Supply Manufacturing (327113)
26. Ceramic Wall and Floor Tile Manufacturing (327122)
27. Other Structural Clay Product Manufacturing (327123)
28. Nonclay Refractory Manufacturing (327125)
29. Flat Glass Manufacturing (327211)
30. Other Pressed/Blown Glass and Glsswr. Mfg. (327212)
31. Glass Container Manufacturing (327213)
32. Cement Manufacturing (327310)
33. Lime Manufacturing (327410)
34. Ground or Treated Mineral and Earth Mfg. (327992)
35. Mineral Wool Manufacturing (327993)
36. Iron and Steel Mills (331111)
37. Electrometallurgical Ferroalloy Product Mfg. (331112)
38. Iron/Steel Pipe/Tube Mfg. from Purchsd. Steel (331210)
39. Alumina Refining (331311)
40. Primary Aluminum Production (331312)
41. Primary Smelting and Refining of Copper (331411)
42. Smltg./Rfg. of Nonfrs. Mtl. (ex. Cpr. and Almn.) (331419)
43. Iron Foundries (331511)
44. Carbon and Graphite Product Manufacturing (335991)
45. Iron Ore Mining (212210)
46. Copper Ore and Nickel Ore Mining (212234)

Stylized fact #5: Resource extraction is not optimal (Haiti/DR)

Stylized fact #6: Energy and Environment and Intertwined



Stylized fact #7: Global CO2 per GDP is a linear trend



Agenda for today

- Stylized facts in pictures
- **Quick overview of trade+environment**
- Toy model
- Paper: Trade policy and climate change
- Paper: Why is pollution declining?

Quick overview of trade+environment: classic

- 1970s: highly stylized–Pethig, Markusen
- 1994: NAFTA
  - Grossman and Krueger (QJE 1995)
  - Environmental Kuznets Curve
  - Scale, composition, technique
  - Note Harbaugh & Levinson (ReStat 2002)
- Copeland & Taylor
  - Summary: 2005 book ("Trade and the Environment", Princeton UP)
  - Is Free Trade Good for the Environment?

Quick overview of trade+environment: recent

- Overviews: Cherniwchan, Copeland, Taylor (Annual Reviews of Economics); Copeland, Shapiro, Taylor (Handbook of International Economics forthcoming)
- Does trade help climate change adaptation?
  - Costinot, Donaldson, Smith (JPE 2016)
  - Dingel, Hsiang, Meng (WP)
- How does trade affect pollution emissions?
  - Shapiro and Walker (AER 2018)
- How should trade policy and climate change policy interact?
  - Nordhaus (AER 2015)
  - Shapiro (QJE 2021)
  - Hsiao (WP)
- How do dynamic spatial models improve analysis of climate change?
  - Balboni (WP)
  - Alvarez, Rossi-Hansberg (WP)

Agenda for today

- Stylized facts in pictures
- Quick overview of trade+environment
- **Toy model**
- Paper: Trade policy and climate change
- Paper: Why is pollution declining?

Toy model (Armington)

- Canonical (here: ACR, "New Trade Models, Same Old Gains?" AER 2012)
- Preferences:

$$U_j = \left[\sum_{i=1}^{n} q_{ij}^{(\sigma-1)/\sigma} \right]^{\sigma/(\sigma-1)}$$

- Price index:

$$P_j = \left[\sum_{i=1}^{n} (w_i \tau_{ij})^{1-\sigma} \right]^{1/(1-\sigma)}$$

- Trade flows:

$$X_{ij} = \left(\frac{w_i \tau_{ij}}{P_j} \right)^{1-\sigma} Y_j$$

- Trade balance:

$$Y_i = w_i L_i$$

- Change in real income:

$$\hat{W}_j = \hat{\lambda}_{jj}^{1/(1-\sigma)}$$

Toy model: trade extensions (“structural gravity”)

- Many industries, input-output links, trade imbalances, multiple factors (straightforward)
- Productivity as a source of comparative advantage (Ricardian/Eaton-Kortum)
- Monopolistic competition with homogeneous firms (Krugman 1980)
- Monopolistic competition with heterogeneous firms (Melitz)
- Goods moving between cities, people commuting between neighborhoods (Economic geography)

Toy model: environmental/energy extensions

- Firms emit pollution but pollution is regulated (Shapiro & Walker AER 2018)
- Climate clubs: trade policy supports global climate policy (Nordhaus AER 2015)
- Trade equalizes prices, helps agricultural adaptation to climate change (Costinot & Donaldson JPE 2016)
- Tariffs, non-tariff barriers chosen for political economy reasons (Shapiro QJE 2021)

Agenda for today

- Stylized facts in pictures
- Quick overview of trade+environment
- Toy model
- **Paper: Trade policy and climate change**
- Paper: Why is pollution declining?

The Environmental Bias of Trade Policy

Joseph S. Shapiro
UC Berkeley and NBER

Motivation

- **Need global policy, have regional policy**
  - 20% of global carbon emissions face carbon prices (EU, California, etc.)
  - Leakage a big concern
- **Carbon tariffs a possible solution**
  - Waxman-Markey (2009) Bill, California's AB32
  - France, Mexico, Canada recent threats
- **Do countries already have higher tariffs / non-tariff barriers on dirty industries?**
  - Plausible: dirty industries are politically influential
  - Implicitly, would resemble carbon tariffs

Overview

1. **One new fact, three ways to say it**
   - Countries have higher tariffs and non-tariff barriers on clean than dirty goods
     - "Dirty" based on tons CO_2 emissions to produce $1 output
   - Countries implicitly have carbon border adjustments, but they are subsidies
   - Trade policy implicitly subsidizes climate change
     - Global implicit carbon subsidy in trade: $85 to $120/ton
2. **Political Economy Explanations**
3. **Consequences**

Overview

1. **One new fact, three ways to say it**
2. **Political Economy Explanations**
   - Little role for standard stories (unionization, optimal tariffs, etc.)
   - Main story: downstream industries have lower emissions, higher tariffs
   - Interpretation: upstream-downstream lobbying
3. **Consequences**

Overview

1. **One new fact, three ways to say it**

2. **Political Economy Explanations**

   American manufacturers, energy companies, and retailers reliant on cheap steel are quietly lobbying against President Donald Trump's desire to impose tariffs on steel imports ahead of possible decision by the U.S. Commerce Department next week. . . . U.S. manufacturers and energy companies who use steel want to keep their costs down and say tariffs could cost jobs in their industries . . .

   – Reuters 7/14/2017, "Behind the scenes, companies fight Trump on U.S. steel tariffs"

3. **Consequences**

Overview

1. **One new fact, three ways to say it**
2. **Political Economy Explanations**
3. **Consequences**
   - Global implicit subsidy to $CO_2 >$ \$500 billion / year
   - Same trade policy for clean, dirty industries would decrease global CO_2, increase GDP

Interpretation

- **Is this a subsidy?**
  - Relative subsidy: lower taxes in setting with mostly positive taxes
  - Quantitative model: this environmental bias increases global CO_2
- **Possible mechanisms to affect CO_2**
  - Traded goods dirtier due to transportation, outsourcing to India/China
  - Substitution between producing/consuming goods (e.g., aluminum/steel)
  - Broadly, sends wrong price signal
  - Agents respond in many ways, paper models some

What is New Here

- **Trade and the environment; Industrial ecology** (Copeland and Taylor 2003; Fowlie et al. 2016; Kortum and Weisbach 2016; Shapiro and Walker 2017)
  - New: compare trade policy to pollution embodied in goods
- **Political economy and environment** (Hillman and Ursprung 1994; Oates and Portney 2003; Schleich and Orden 2000; Burgess et al. 2012; Sallee 2017)
  - New: trade policy as setting for political economy and the environment
- **Trade policy** (Grossman and Helpman 1994; Goldberg and Maggi 1999; Copeland 2000; Gawande and Bandyopadhyay 2000; Ederington 2010; Gawande et al. 2012; Maggi 2016)
  - New: addressing tariff escalation slows climate change
  - NTB escalation, nonparametric tariff escalation
- **Quantitative General Equilibrium Models** (Krugman 1980; Grossman and Helpman 1994; Costinot and Rodríguez-Clare 2014; Ossa 2014; Caliendo, Parro, and Tsyvinski 2017; Caron and Fally 2018)

Overview

- **Data**
- Econometrics
- Trade Policy and Carbon Intensity
- Explanations for Tariff-Pollution Relationship
- Consequences of Tariff-Pollution Relationship

Data: Trade Policy

- **Global tariffs**
  - CEPII Macmap, 200 million observations
  - 192 countries, 5,000 products (6-digit Harmonized System codes)
  - Tariffs, trade agreements, customs unions, tariff-rate quotas, etc.
- **U.S. import tariffs**
  - Source: U.S. Census Imports of Merchandise series
  - 375 industries (6-digit NAICS for manufacturing)

Data: Trade Policy

- **Non-tariff barriers (NTBs)**
  - What are NTBs? Quotas, product standards, licenses, etc.
  - Source: Kee et al. (2009) Ad valorem equivalents Kee details
  - Widely used (Irwin 2010; Limao and Tovar 2011; Novy 2013; Handley 2014)
  - Bagwell and Staiger (2011): "the best [NTB] measures that are available"
  - 5,000 products (6-digit Harmonized System codes)
  - One year per country, in 2000-2003

Data: Pollution Emissions

- **Measuring CO_2 emissions, national data**

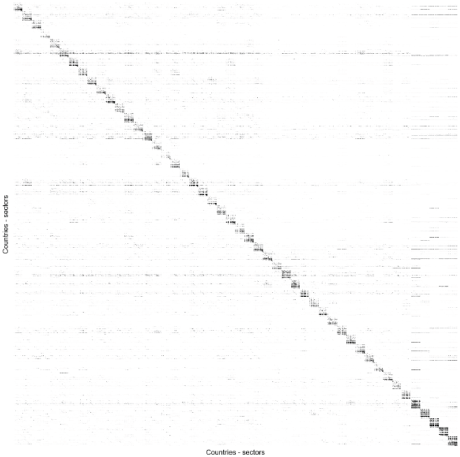
$$\begin{aligned} x &= Ax + d \\ (I - A)x &= d \\ x &= (I - A)^{-1} d \\ E &= e(I - A)^{-1} d \end{aligned}$$

- **Definitions:**

x	Gross output ($S \times 1$)
A	Input-output matrix ($S \times S$)
d	Final demand, including exports ($S \times 1$)
e	Tons CO_2 emitted per dollar of fuel input ($S \times S$, diagonal)
E	Tons CO_2 emitted per dollar of industry output ($S \times 1$)

Data: Global Pollution Emissions

- **Total emissions, global**
  - Exiobase, a multi-region input-output database
  - Year 2007, 61 million trade flows (48 countries, 163 industries)



Data: U.S. Pollution Emissions

- **Total emissions, U.S. 2007**
  - Input-output table from Bureau of Economic Analysis
  - Energy Information Agency: emissions per physical unit of coal/oil/gas
  - Combine Make, Use tables; exclude feedstock

- **Direct U.S. emissions**
  - Manufacturing Energy Consumption Survey (MECS) and Census of Manufactures (CM)
  - Physical consumption of coal, oil, gas by NAICS industry
  - Census of Manufactures (CM) : electricity consumption and cost of fuels

Data: Trade Policy and Pollution Emissions

Table 1—Cleanest and Dirtiest Manufacturing Industries in Global Data

	CO_2 Rate (Tons/$)×1000 (1)	Import Tariff Rate (2)	Non-Tariff Barriers (3)
Panel A. Cleanest industries			
Pork processing	0.34	0.10	0.37
Meat products n.e.c.	0.36	0.10	0.37
Sugar refining	0.37	0.20	0.42
Wood products	0.37	0.01	0.03
Motor vehicles	0.40	0.03	0.05
Mean of cleanest 5 industries	*0.37*	*0.09*	*0.25*
Panel B. Dirtiest industries			
Bricks, tiles	1.54	0.02	0.02
Coke oven products	1.64	0.01	0.01
Iron and steel	1.74	0.01	0.02
Phosphorus fertilizer	1.93	0.02	0.11
Nitrogen fertilizer	2.53	0.02	0.11
Mean of dirtiest 5 industries	*1.88*	*0.02*	*0.05*

Data: Tariffs and Pollution Emissions

Table 1—Cleanest and Dirtiest Manufacturing Industries in Global Data

	CO_2 Rate (Tons/\$)×1000 (1)	Import Tariff Rate (2)	Non-Tariff Barriers (3)
Panel A. Cleanest industries			
Pork processing	0.34	0.10	0.37
Meat products n.e.c.	0.36	0.10	0.37
Sugar refining	0.37	0.20	0.42
Wood products	0.37	0.01	0.03
Motor vehicles	0.40	0.03	0.05
Mean of cleanest 5 industries	*0.37*	*0.09*	*0.25*
Panel B. Dirtiest industries			
Bricks, tiles	1.54	0.02	0.02
Coke oven products	1.64	0.01	0.01
Iron and steel	1.74	0.01	0.02
Phosphorus fertilizer	1.93	0.02	0.11
Nitrogen fertilizer	2.53	0.02	0.11
Mean of dirtiest 5 industries	*1.88*	*0.02*	*0.05*

Data: Tariffs and Pollution Emissions

Table 1—Cleanest and Dirtiest Manufacturing Industries in Global Data

	CO_2 Rate (Tons/$)×1000 (1)	Import Tariff Rate (2)	Non-Tariff Barriers (3)
Panel A. Cleanest industries			
Pork processing	0.34	0.10	0.37
Meat products n.e.c.	0.36	0.10	0.37
Sugar refining	0.37	0.20	0.42
Wood products	0.37	0.01	0.03
Motor vehicles	0.40	0.03	0.05
Mean of cleanest 5 industries	*0.37*	*0.09*	*0.25*
Panel B. Dirtiest industries			
Bricks, tiles	1.54	0.02	0.02
Coke oven products	1.64	0.01	0.01
Iron and steel	1.74	0.01	0.02
Phosphorus fertilizer	1.93	0.02	0.11
Nitrogen fertilizer	2.53	0.02	0.11
Mean of dirtiest 5 industries	*1.88*	*0.02*	*0.05*

Data: Political Economy Variables

- **Optimal tariffs**: Inverse export supply elasticities. Bickerdike (1907); Broda, Limao, and Weinstein (2008)
- **Lobbying supply**: Four-firm concentration ratio; mean firm size; standard deviation of firm size; capital share; shipping cost; geographic dispersion; workers unionized; workers unemployed; PAC contributions
- **Demand for protection** Output trends; import penetration ratio; import penetration ratio trends; labor share; workers college share; workers mean wages
- **Demand for low protection from customers**: Intra-industry trade, upstreamness
- **Upstreamness**: Simple measure; Antras et al. (2012)

$$
\begin{aligned}
U_i^S &= \sum_{j=1}^{n} \Omega_{ij} y_j / y_i \\
U_i^D &= [I - \Omega_{ij} y_j / y_i]^{-1} \mathbf{1}
\end{aligned}
$$

Overview

- Data
- **Econometrics**
- Trade policy and carbon intensity
- Explanations for tariff-pollution relationship
- Consequences of tariff-pollution relationship

Econometrics: Implicit Carbon Subsidies

Basic Equation

$$t_{js} = \alpha E_{js} + \zeta_j + \varepsilon_{js}$$

Notes

- Averages over exporters (average excludes intra-national trade)
- α is carbon tax implicit in trade policy (\$ per ton CO_2)
- Carbon tax reflects industry emissions (not firm). May not reflect abatement.
- Importer chooses tariffs, exporter determines emissions.
- Heteroskedastic-robust standard errors (appendix: cluster by country)
- Main analysis: manufacturing only
- Data for year 2007
- U.S.: instrument E with E^{direct} to address measurement error:

$$E_{js} = \alpha E_{js}^{direct} + X_{js}'\beta + \varepsilon_{js}$$

Econometrics: Political Economy

Basic Equation

$$t_{js} = \alpha E_{js} + F'_{js}\pi + \mu_j + \varepsilon_{js}$$

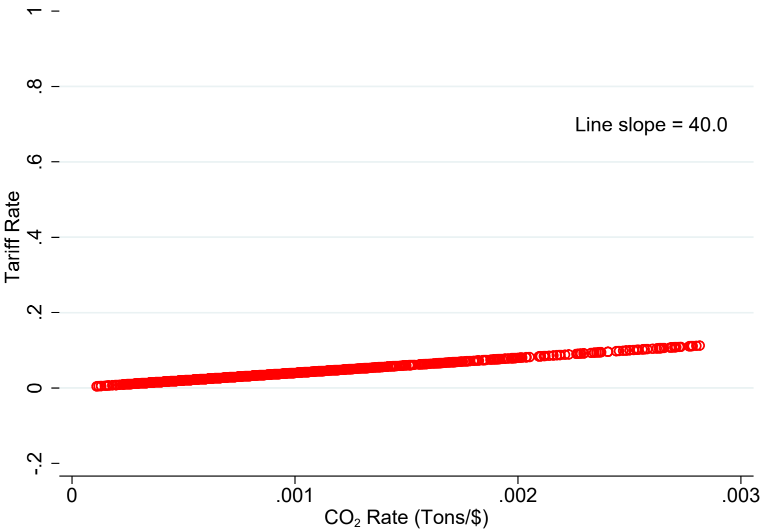
Details:

- F political economy explanations
- Focus on U.S.–better political economy and other data
- Lasso (machine learning) and OLS

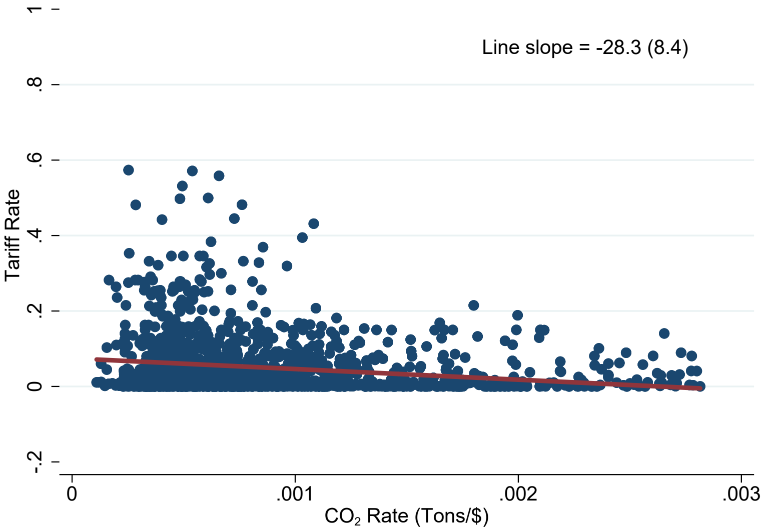
Overview

- Data
- Econometrics
- **Trade Policy and Carbon Intensity**
  - **Tariffs**
  - Non-tariff barriers
  - Tariffs + non-tariff barriers
  - Extensions
- Explanations for Tariff-Pollution Relationship
- Consequences of Tariff-Pollution Relationship

Hypothetical Carbon Border Adjustment with $40/Ton Carbon Tax

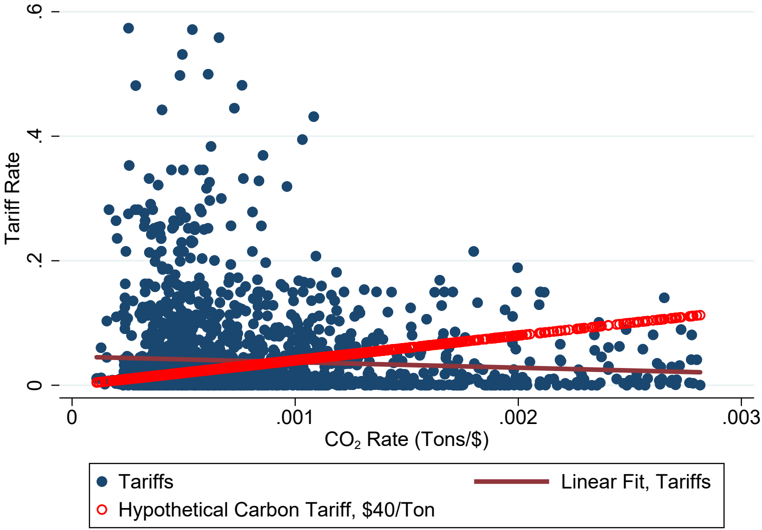


Results: Actual Global Tariffs Versus Carbon Intensity



Graph with weights

Results: Actual Global Tariffs Versus Carbon Intensity



Results: Carbon Taxes Implicit in Import Tariffs

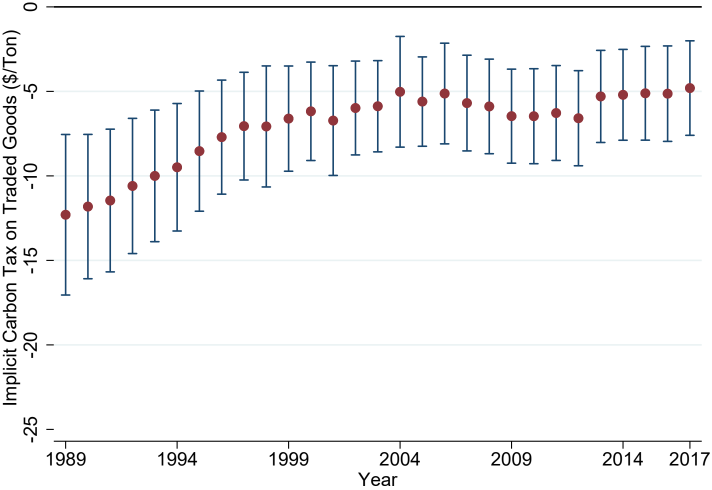
$t_{js} = \alpha E_{js} + \zeta_j + \varepsilon_{js}$

Table 2—Association of Import Tariffs and CO_2 Emissions Rates

	FS		RF		OLS		IV	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A. All global trade (global input-output table)								
CO_2 rate	1.38***	1.54***	-44.53***	-17.19**	-28.28***	-4.48	-32.25***	-11.17**
	(0.09)	(0.08)	(13.13)	(8.15)	(8.42)	(6.17)	(8.37)	(5.40)
N	2,021	2,021	2,021	2,021	2,021	2,021	2,021	2,021
Dependent Var. Mean	0.001	0.001	0.052	0.028	0.052	0.028	0.052	0.028
K-P F Statistic	—	—	—	—	—	—	232.65	352.34
Panel B: U.S. Imports (U.S. data)								
CO_2 rate	1.32***	1.58***	-7.52***	-10.35***	-4.89***	-3.23***	-5.69***	-6.55***
	(0.19)	(0.51)	(2.00)	(3.71)	(1.40)	(0.94)	(1.44)	(2.29)
N	379	379	379	379	379	379	379	379
Dependent Var. Mean	0.001	0.001	0.018	0.016	0.016	0.018	0.018	0.016
K-P F Statistic	—	—	—	—	—	—	50.33	9.77
Weighted		X		X		X		X

Results: Tariff Rates Versus Carbon Intensity, U.S. Import Tariffs 1989-2017

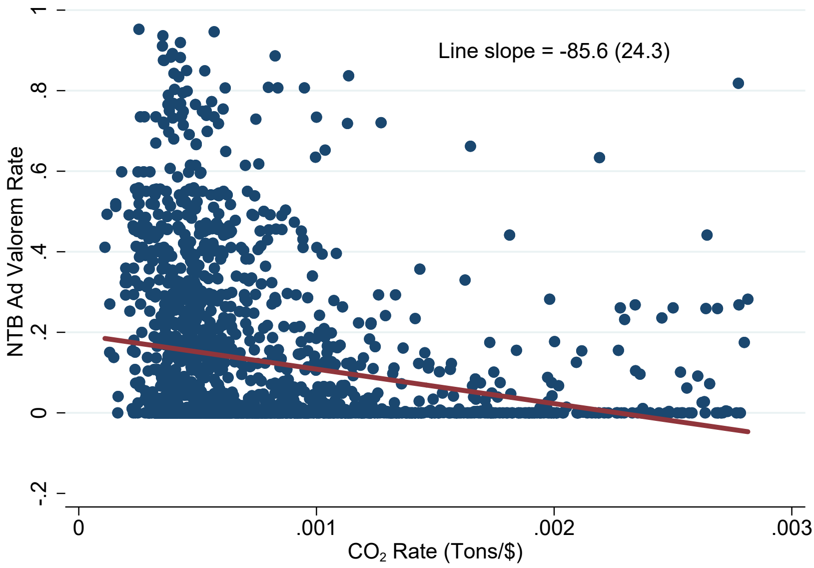
$t_{js} = \alpha E_{js} + \zeta_j + \varepsilon_{js}$



Overview

- Data
- Econometrics
- **Trade Policy and Carbon Intensity**
  - Tariffs
  - **Non-tariff barriers**
  - Tariffs + non-tariff barriers
  - Extensions
- Explanations for Tariff-Pollution Relationship
- Consequences of Tariff-Pollution Relationship

Results: Carbon Taxes Implicit in Global Non-Tariff Barriers



Results: Carbon Taxes Implicit in Non-Tariff Barriers

$t_{js} = \alpha E_{js} + \zeta_j + \varepsilon_{js}$

Table 3—Association of Non-Tariff Barriers and CO_2 Emissions Rates

	FS		RF		OLS		IV	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A. All global trade (global input-output table)								
CO_2 rate	1.38***	1.54***	-124.01***	-116.47**	-85.58***	-73.22*	-89.82***	-75.67**
	(0.09)	(0.08)	(40.72)	(43.79)	(24.33)	(36.75)	(26.73)	(29.38)
N	2,021	2,021	2,021	2,021	2,021	2,021	2,021	2,021
Dep. Var. Mean	0.001	0.001	0.126	0.088	0.126	0.088	0.126	0.088
K-P F Statistic	—	—	—	—	—	—	232.65	352.34
Panel B. U.S. imports (U.S. data)								
CO_2 rate	1.32***	1.58***	-63.34***	-59.13***	-41.04***	-17.98***	-47.96***	-37.41***
	(0.19)	(0.51)	(16.68)	(20.78)	(7.44)	(4.15)	(10.03)	(12.33)
N	379	379	379	379	379	379	379	379
Dep. Var. Mean	0.001	0.001	0.109	0.079	0.109	0.079	0.109	0.079
K-P F Statistic	—	—	—	—	—	—	50.33	9.77
Weighted		X		X		X		X

Overview

- Data
- Econometrics
- **Trade Policy and Carbon Intensity**
  - Tariffs
  - Non-tariff barriers
  - **Tariffs+Non-tariff barriers**
  - Extensions
- Explanations for Tariff-Pollution Relationship
- Consequences of Tariff-Pollution Relationship

Results: Total Implicit Carbon Taxes, by Country

$t_s = \alpha_j E_s + \varepsilon_s$

Appendix Table 1—Carbon Taxes Implicit in Trade Policy, Sensitivity Analysis

	Global				US Imports			
	Tariffs		NTBs		Tariffs		NTBs	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1. Main estimates	-32.25***	-11.17**	-89.82***	-75.67**	-5.69***	-6.55***	-47.96***	-37.41***
	(8.56)	(5.52)	(27.32)	(30.02)	(1.44)	(2.30)	(10.06)	(12.36)
Other econometrics								
2. Tobit (no IV)	-35.63***	-5.29	-157.58***	-146.00**	-6.19***	-3.61***	-270.19***	-156.78***
	(11.52)	(6.09)	(40.74)	(59.37)	(1.96)	(1.30)	(60.86)	(56.43)
3. Tobit (IV)	-44.24***	-11.57**	-191.41***	-154.32**	-7.22***	-10.04***	-480.32***	-369.11**
	(15.51)	(5.74)	(56.45)	(70.20)	(2.29)	(3.59)	(132.43)	(158.31)
4. Standard errors	-32.25***	-11.17***	-89.82***	-75.67***	—	—	—	—
clustered by importer	(7.70)	(3.30)	(11.69)	(12.84)	—	—	—	—
Nonlinearity								
5. Logs	-0.66	-0.91**	-0.09***	-0.02	-0.64*	-0.22	-0.07***	-0.04*
	(0.45)	(0.43)	(0.03)	(0.05)	(0.36)	(0.59)	(0.02)	(0.02)
Weighted		X		X		X		X

Results: Total Implicit Carbon Taxes, by Country

$$t_s = \alpha_j E_s + \varepsilon_s$$

Appendix Table 1—Carbon Taxes Implicit in Trade Policy, Sensitivity Analysis

	Global				US Imports			
	Tariffs		NTBs		Tariffs		NTBs	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
6. Quadratic in emissions								
no IV. CO_2 rate	-58.33***	3.58	-194.52***	-152.31	-10.15**	-1.29	-45.45*	8.17
	(20.32)	(14.81)	(55.98)	(113.86)	(4.65)	(5.63)	(25.49)	(27.49)
CO_2 rate^2	9,539.88**	-3,508.35	34,582.94**	34,420.37	1,260.10	-355.19	1,055.59	-4,798.88
	(4,668.97)	(4,695.02)	(14,405.20)	(34,372.49)	(807.49)	(882.31)	(5,166.68)	(4,704.39)
fitted slope, 10th pct.	-51.56	1.09	-169.99	-127.89	-9.22	-9.22	4.62	4.62
fitted slope, 50th pct.	-46.70	-0.70	-152.35	-110.34	-8.22	-8.22	0.82	0.82
fitted slope, 90th pct.	-30.26	-6.74	-92.77	-51.04	-4.86	-4.86	-11.99	-11.99
7. Nonparametric marginal effect (no IV)	-18.56	—	-81.48	—	-4.89	-4.89	-41.04	-41.04
<u>Other data cleaning and aggregation</u>								
8. Winsorize dependent, independent variables	-25.45***	-10.66*	-90.40***	-75.69**	-5.75***	-6.42***	-51.40***	-38.01***
	(6.57)	(5.39)	(27.72)	(29.95)	(1.62)	(2.29)	(10.45)	(12.69)
9. Include non-manuf. industries	-32.32***	-9.9	-84.18***	-72.75**	—	—	—	—
	(8.60)	(8.95)	(24.00)	(33.10)	—	—	—	—
Weighted		X		X		X		X

Results: Total Implicit Carbon Taxes, by Country

$t_s = \alpha_j E_s + \varepsilon_s$

Appendix Table 1—Carbon Taxes Implicit in Trade Policy, Sensitivity Analysis

	Global				US Imports			
	Tariffs		NTBs		Tariffs		NTBs	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
10. Multiple partners	-37.21**	-11.24*	-82.46**	-75.70**	-6.95***	-6.55***	-55.10***	-37.41***
(i×j×s level data)	(16.43)	(5.84)	(32.10)	(29.64)	(2.10)	(2.29)	(12.34)	(12.34)
11. i×j×s level data	-38.23**	-16.35**	-84.30**	-93.60**	-6.54***	-2.61*	-54.23***	-38.40***
exporter fixed effects	(17.05)	(6.88)	(33.07)	(37.44)	(1.95)	(1.41)	(11.87)	(14.13)
12. Industry-level data	-21.80**	-12.77**	-124.16**	-78.08*	—	—	—	—
(no IV)	(10.38)	(5.14)	(52.71)	(45.14)	—	—	—	—
13. Add intra-national	-5.80***	-11.75***	-60.42**	-80.99***	—	—	—	—
trade	(1.39)	(3.83)	(23.29)	(20.72)	—	—	—	—
<u>Other measures of emissions</u>								
14. Direct emissions	-27.48***	-11.53	-78.33***	-104.70***	-3.86***	-3.40***	-36.32***	-19.93***
	(7.91)	(8.10)	(22.30)	(34.86)	(1.17)	(0.64)	(7.69)	(3.81)
15. Direct emissions	49.89*	-21.03	183.49**	6.37	4.88	-0.98	32.70**	-13.82
	(28.79)	(24.12)	(78.40)	(135.57)	(3.07)	(2.98)	(14.45)	(16.18)
Total emissions	-62.72**	6.55	-212.24***	-76.56	-7.83***	-2.54	-61.79***	-6.42
	(26.28)	(16.00)	(70.42)	(100.21)	(2.96)	(3.65)	(14.68)	(17.43)
16. Include all	-16.87***	-6.55**	-46.72***	-41.65**	—	—	—	—
greenhouse gases	(4.48)	(2.56)	(14.34)	(16.96)	—	—	—	—

Results: Total Implicit Carbon Taxes, by Country

$t_s = \alpha_j E_s + \varepsilon_s$

Appendix Table 1—Carbon Taxes Implicit in Trade Policy, Sensitivity Analysis

	Global				US Imports			
	Tariffs		NTBs		Tariffs		NTBs	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Consumption emissions from energy-consuming durable goods								
17. Exclude energy-consuming durables	-35.23***	-16.50**	-98.52***	-113.23**	-9.60***	-17.40***	-60.92***	-66.09***
	(9.34)	(7.89)	(29.78)	(47.39)	(2.10)	(6.50)	(14.00)	(23.26)
18. Adjust CO_2 rates: 50% goods, 50% energy	-32.85***	-12.33**	-91.08***	-83.46**	-6.04***	-8.34**	-50.89***	-47.66***
	(8.69)	(6.03)	(27.85)	(33.52)	(1.55)	(3.32)	(11.11)	(16.07)
19. Adjust CO_2 rates: 5% goods, 95% energy	-32.65***	-12.02**	-90.55***	-81.34**	-6.39***	-11.07*	-53.86***	-63.25**
	(8.66)	(5.90)	(27.67)	(32.39)	(1.67)	(6.29)	(12.31)	(30.48)
Additional sensitivity analyses								
20. Reverse regression (no IV)	-0.0004***	-0.0002	-0.0006***	-0.0003**	-0.0040***	-0.0040***	-0.0009	-0.0009
	(0.0001)	(0.0004)	(0.0001)	(0.0001)	(0.0011)	(0.0011)	(0.0006)	(0.0006)
21. Lifecycle tariffs	-7.81**	-5.05	-89.72***	-51.38**	—	—	—	—
	(3.55)	(9.30)	(26.98)	(25.25)	—	—	—	—
Weighted		X		X		X		X

Results: Total Implicit Carbon Taxes, by Country

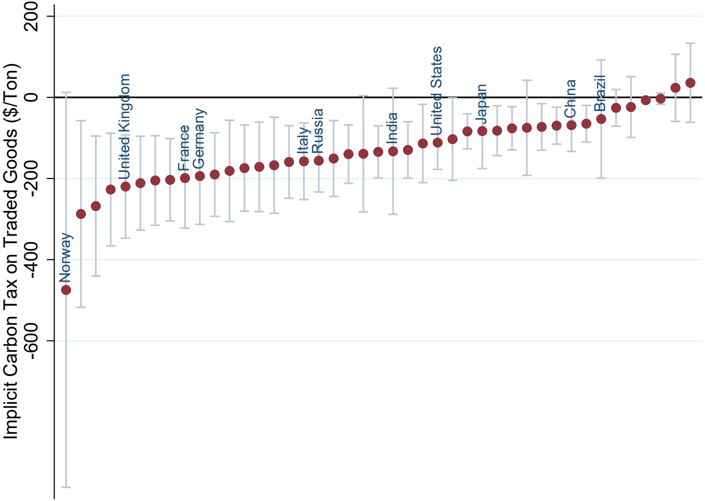
$$t_s = \alpha_j E_s + \varepsilon_s$$

Appendix Table 1—Carbon Taxes Implicit in Trade Policy, Sensitivity Analysis

	Global				US Imports			
	Tariffs		NTBs		Tariffs		NTBs	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
22. No importer fixed effects	-32.11***	-13.53*	-97.58	-83.64***	—	—	—	—
	(8.43)	(7.18)	(55.30)	(30.54)	—	—	—	—
23. WIOD, not Exiobase (no IV)	-13.43	-19.88	-9.24	-121.44	—	—	—	—
	(12.87)	(16.83)	(38.12)	(84.18)	—	—	—	—
24. Add industry fixed effects	11.73	-2.12	-16.07	38.81	—	—	—	—
	(13.89)	(10.49)	(13.39)	(28.76)	—	—	—	—
25. Exclude manuf. food, ag. goods	-5.29	-5.87	-75.67**	-40.78**	-5.70***	-6.68***	-36.55***	-37.67***
	(6.09)	(4.52)	(30.02)	(17.35)	(1.47)	(2.33)	(8.87)	(12.22)
Trade war in 2018								
26. U.S. tariffs in 2017	—	—	—	—	-4.80***	-4.14**	—	—
	—	—	—	—	(1.68)	(1.45)	—	—
27. U.S. tariffs including 2018 protectionism	—	—	—	—	-3.97***	-4.29**	—	—
	—	—	—	—	(1.43)	(1.75)	—	—
Weighted		X		X		X		X

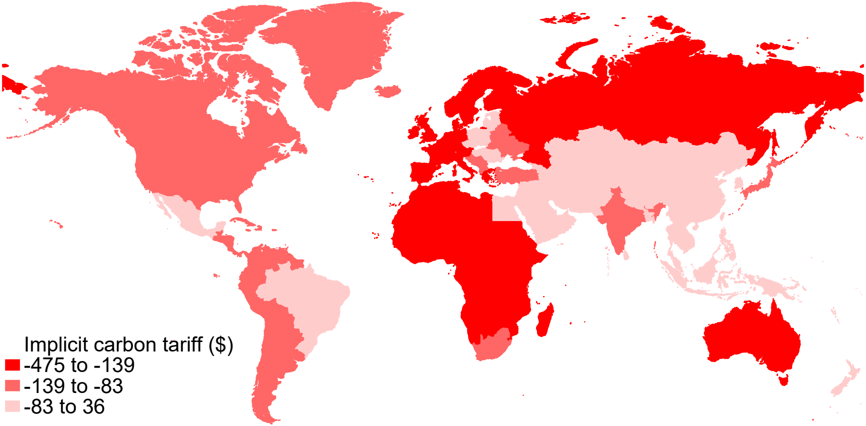
Results: Total Implicit Carbon Taxes, by Country

$t_s = \alpha_j E_s + \varepsilon_s$



Results: Total Implicit Carbon Taxes, by Country

$$t_s = \alpha_j E_s + \varepsilon_s$$



Overview

- Data
- Econometrics
- **Trade Policy and Carbon Intensity**
  - Tariffs
  - Non-tariff barriers
  - Tariffs+Non-tariff barriers
  - **Extensions**
- Explanations for Tariff-Pollution Relationship
- Consequences of Tariff-Pollution Relationship

Cooperative Versus Noncooperative Tariffs

Appendix Table 3—Carbon Taxes Implicit in Cooperative Versus Non-Cooperative Tariffs

	Cooperative		Non-Cooperative	
	(1)	(2)	(3)	(4)
Panel A. U.S. import tariffs				
CO_2 rate	-8.20***	-6.25**	-75.59***	-62.07**
	(2.37)	(2.63)	(15.05)	(28.61)
N	382	382	382	382
Dep. Var. Mean	0.030	0.020	0.322	0.289
Panel B. Japanese import tariffs				
CO_2 rate	-58.93***	-49.13*	-66.29***	-41.91
	(17.92)	(28.12)	(19.25)	(25.68)
N	47	47	47	47
Dep. Var. Mean	0.084	0.044	0.09	0.046
Panel C: Chinese import tariffs				
CO_2 rate	8.37	23.67	-161.29**	-143.42*
	(13.53)	(17.61)	(63.32)	(83.86)
N	47	47	47	47
Dep. Var. Mean	0.100	0.068	0.601	0.491
Weighted		X		X

Overview

- Data
- Econometrics
- Trade Policy and Carbon Intensity
- **Explanations for Tariff-Pollution Relationship**
- Consequences of Tariff-Pollution Relationship

Political Economy Explanations

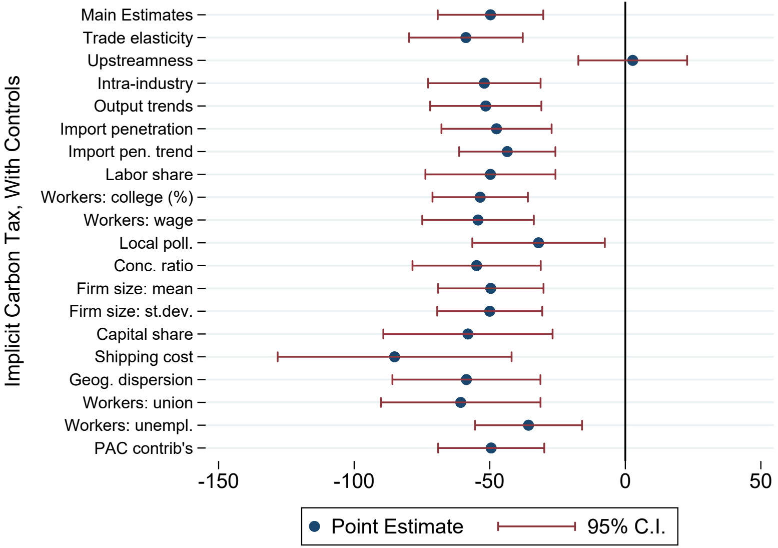
$$t_{js} = \alpha E_{js} + F_{js}'\gamma + \zeta_j + \varepsilon_{js}$$

Table 4—Political Economy Explanations for Implicit Carbon Taxes

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. All global trade						
CO_2 rate	-120.53***	-32.86	-120.74***	-121.45***	-120.90***	-120.41***
	(33.69)	(25.61)	(33.13)	(35.48)	(34.08)	(33.58)
N	1,990	1,990	1,990	1,990	1,990	1,990
Panel B. All global trade, instrument for political economy						
CO_2 rate	-120.53***	34.03	-111.90***	-125.82***	-102.61**	-119.35***
	(33.69)	(38.64)	(39.44)	(47.27)	(43.26)	(33.86)
K-P F Statistic	—	45.09	31.09	42.03	10.94	22.71
N	1,990	1,990	1,990	1,990	1,990	1,990
Panel C. U.S. imports						
CO_2 rate	-49.72***	2.74	-51.99***	-47.50***	-49.75***	-54.32***
	(9.90)	(10.19)	(10.54)	(10.32)	(12.19)	(10.45)
N	358	358	358	358	358	358
Upstreamness		X				
Intra-industry			X			
Import pen. ratio				X		
Labor share					X	
Mean wage						X

Political Economy Explanations

$$t_{is} = \alpha E_{is} + F'_{is}\gamma + \zeta_i + \varepsilon_{is}$$



Global values

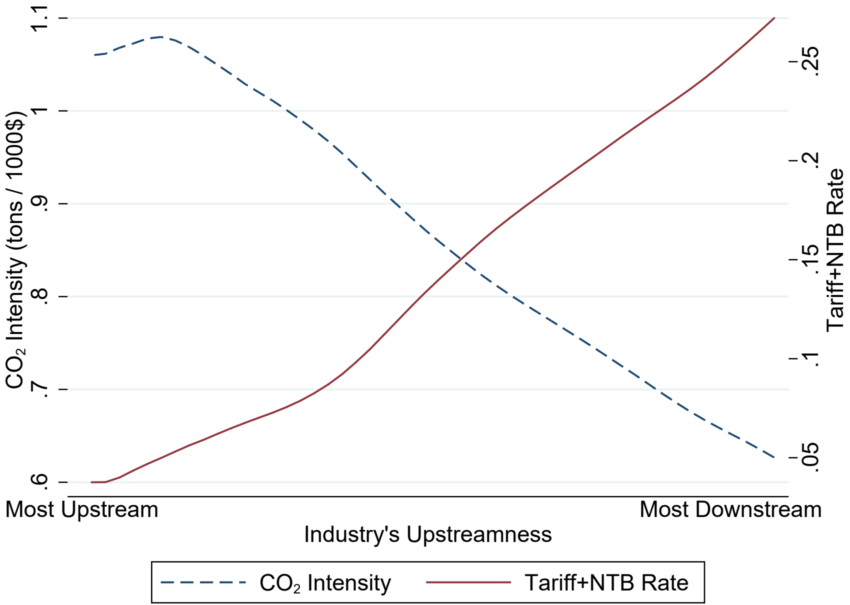
Political Economy Explanations

$$t_{js} = \alpha E_{js} + F'_{js}\gamma + \zeta_j + \varepsilon_{js}$$

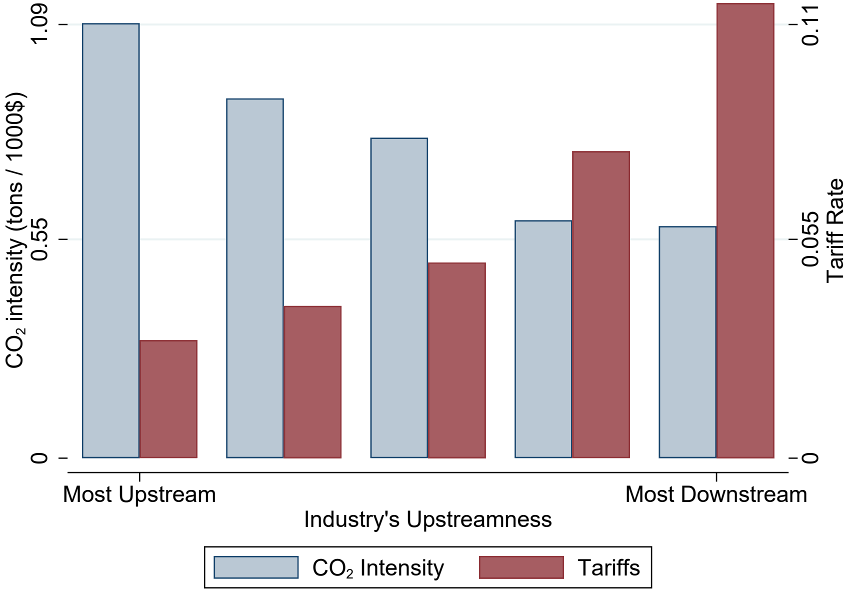
Appendix Table 5—Political Economy Explanations: All Controls Together

	All global trade			U.S. imports	
	IV	IV	Lasso	IV	Lasso
	(1)	(2)	(3)	(4)	(5)
CO_2 rate	-29.237	-28.083	-24.780	-112.754*	-44.065
	(19.444)	(29.538)	(18.726)	(64.063)	(41.779)
Upstreamness	-0.105***	-0.179***	-0.106***	-0.044***	-0.069***
	(0.017)	(0.029)	(0.017)	(0.016)	(0.015)
Intra-industry trade	-0.004	-0.052	0	-0.007	0
	(0.010)	(0.050)	0	(0.015)	0
Import penetration ratio	-0.027**	-0.227***	0	-0.016	0
	(0.012)	(0.069)	0	(0.017)	0
Labor share	-0.012*	-0.336**	0	-0.042	0
	(0.006)	(0.144)	0	(0.026)	0
Workers: mean wage	0.003	0.114	0	-0.034*	0
	(0.019)	(0.072)	0	(0.020)	0
Inverse export supply elast.	—	—	—	-0.023**	0
				(0.011)	0
Output trends 1972-2002	—	—	—	0.007	0
				(0.011)	0
Trend in import pen. ratio	—	—	—	0.026	0
				(0.016)	0
Workers: share w/ college	—	—	—	-0.034	0
				(0.028)	0
Four-firm conc. ratio	—	—	—	-0.059	0
				(0.038)	0
Mean firm size	—	—	—	0.109*	0
				(0.061)	0
Standard dev. of firm size	—	—	—	-0.120*	0
				(0.062)	0
Capital share	—	—	—	0.032	0
				(0.025)	0
Shipping cost per dollar*km	—	—	—	0.034	0.034
				(0.033)	(0.029)
Geographic dispersion	—	—	—	0.083	0
				(0.053)	0
Workers: unemployed	—	—	—	0.001	0
				(0.028)	0
Workers: unionized (%)	—	—	—	0.025	0
				(0.017)	0
Local pollution				0.008	0
				(0.015)	0
PAC contributions	—	—	—	0.028	0
				(0.021)	0
Instrument political economy		X			

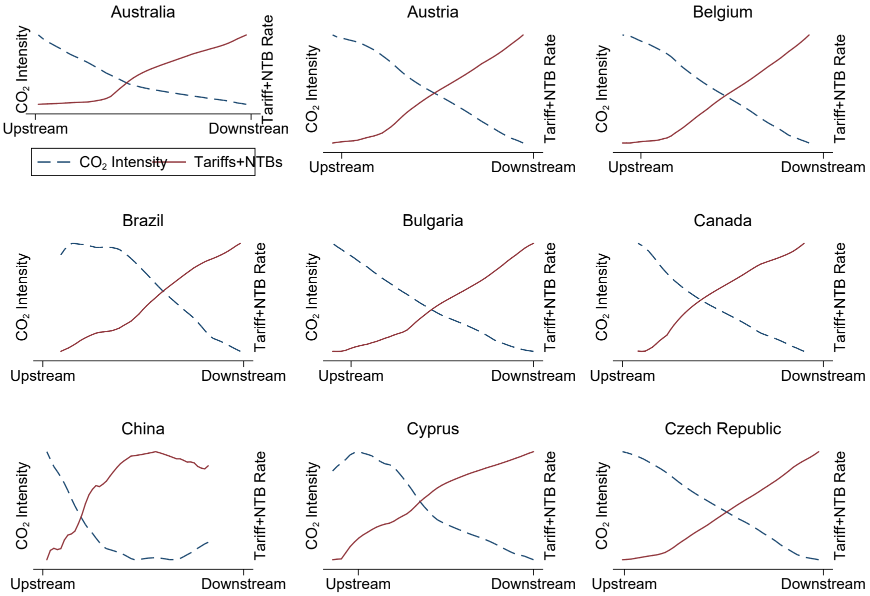
Political Economy Explanations



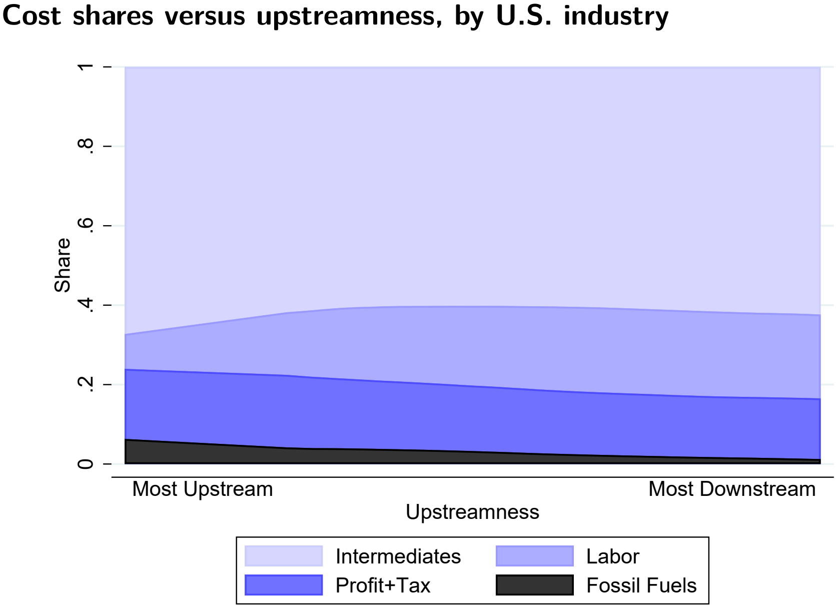
Political Economy Explanations



Political Economy Explanations



Explanations: Why are upstream industries dirtier?



Explanations: Broad View of Theory

- **Non-cooperative theory**
  - Protection for sale (Grossman and Helpman 1994)
  - Political economy motive and terms-of-trade motive
- **Cooperative theory**
  - Trade wars and trade talks (Grossman and Helpman 1995)
  - Commitment (Maggi and Rodriguez-Clare 1998, 2007)
  - Political economy motive remains, terms-of-trade motive diminished
- **Production efficiency (Diamond-Mirrlees 1971)**
  - Can't explain escalation in NTBs
  - Tariff escalation isn't optimal tax

Overview

- Data
- Econometrics
- Trade Policy and Carbon Intensity
- Explanations for Tariff-Pollution Relationship
- **Consequences of Tariff-Pollution Relationship**
  - **Partial equilibrium approximation**
  - Analytical model
  - Quantitative model

Consequences: Partial Equilibrium

Calculation:

$$\sum_{i,s} \hat{\alpha}_j X_{js} E_{js}$$

- Recall, α_j implicit subsidy, X_{js} trade flows, E_{js} emissions rate

Result:

- Year 2007: \$550 to \$800 billion subsidy per year
- For reference, total direct subsidies to fossil fuels: \$530 billion/year (IMF 2013)

Overview

- Data
- Econometrics
- Trade Policy and Carbon Intensity
- Explanations for Tariff-Pollution Relationship
- **Consequences of Tariff-Pollution Relationship**
  - Partial equilibrium approximation
  - **Analytical model**
  - Quantitative model

Overview

- Data
- Econometrics
- Trade Policy and Carbon Intensity
- Explanations for Tariff-Pollution Relationship
- **Consequences of Tariff-Pollution Relationship**
  - Partial equilibrium approximation
  - Analytical model
  - **Quantitative model**

Consequences: Quantitative Model

A1: Consumer Preferences

$$U_j = \prod_s \left(\sum_i q_{ijs}^{\frac{\sigma_s - 1}{\sigma_s}} \right)^{\frac{\sigma_s}{\sigma_s - 1}\beta_{js}} [1 + \delta(Z - Z_0)]^{-1}$$

Details:

- Representative agent
- CES across varieties, Cobb-Douglas across sectors
- Climate damages δ calibrated to \$40/ton

Consequences: Quantitative Model

A2: Firms, Production Technology

$$a_{jt} = (L_{jt})^{1-\eta_{is}} \prod_s \left(\sum_o (q^I_{ojst})^{\frac{\sigma_s - 1}{\sigma_s}} \right)^{\frac{\sigma_s}{\sigma_s - 1}\eta_{jst}}$$

Details:

- Aggregate input A: factors and composite intermediates
- Composite intermediates: CES across varieties, Cobb-Douglas input-output

Trade costs: $\phi_{ijt} = \tau_{ijt}(1 + t_{ijt})(1 + n_{ijt})$

Consequences: Quantitative Model

A3: Pollution

$$Z_{is} = \gamma_{is} \frac{R_{is}}{P_{is}}$$

A4: Market Clearing

$$\begin{aligned} L_i &= \sum_s L_{is} \\ \sum_{j,s} X_{ijs} &= \sum_{j,s} X_{jis} - D_i \end{aligned}$$

Consequences: Quantitative Model

Unit costs:

$$c_{is} = w_i^{1-\eta_{is}} \prod_k P_{ik}^{\eta_{iks}}$$

Price index:

$$P_{js} = \left(\sum_i (\phi_{ijs} c_{is})^{\epsilon_s} \right)^{\frac{1}{\epsilon_s}}$$

Expenditure shares:

$$\lambda_{ijs} = \frac{(\phi_{ijs} c_{is})^{\epsilon_s}}{\sum_o (\phi_{ojs} c_{os})^{\epsilon_s}}$$

Expenditure, country-sector

$$X_{js} = \frac{\beta_{js} \left(Y_j + D_j + \sum_{i,l} \frac{t_{ijl}}{1+t_{ijl}} \lambda_{ijl} \sum_k \alpha_{jlk} R_{jk} \right)}{1 - \sum_{i,l} \frac{t_{ijl}}{1+t_{ijl}} \lambda_{ijl} \beta_{jl}} + \sum_k \alpha_{jlk} R_{jk}$$

Consequences: Quantitative Model

Revenue, country-sector

$$R_{is} = \sum_j \frac{\lambda_{ijs}}{1+t_{ijs}} X_{js}$$

National income

$$Y_i = \sum_s (1-\alpha_{is}) R_{is}$$

Consequences: Quantitative Model

Counterfactual Methodology:

- Exact hat algebra (Dekle, Eaton, and Kortum 2008)

$$x_i' = \hat{x}_i x_i$$

Consequences: Quantitative Model

Equilibrium in changes

Unit costs:

$$\hat{c}_{is} = \hat{w}_i^{1-\eta_{is}} \prod_k \hat{P}_{ik}^{\eta_{iks}}$$

Trade shares:

$$\hat{\lambda}_{ijs} = \frac{(\hat{\phi}_{ijs}\hat{c}_{is})^{\epsilon_s}}{\sum_o \lambda_{ojs}(\hat{\phi}_{ojs}\hat{c}_{os})^{\epsilon_s}}$$

Expenditure, country-sector:

$$\hat{X}_{js}X_{js} = \frac{\beta_{js}\left(\hat{w}_j Y_j + D_j + \sum_{i,l} \frac{t'_{ijl}}{1+t'_{ijl}} \hat{\lambda}_{ijl}\lambda_{ijl} \sum_k \alpha_{jlk}\hat{R}_{jk}R_{jk}\right)}{1-\sum_{i,s} \frac{t'_{ijs}}{1+t'_{ijs}} \hat{\lambda}_{ijs}\lambda_{ijs}\beta_{js}} + \sum_k \alpha_{jsk}\hat{R}_{jk}R_{jk}$$

Consequences: Quantitative Model

Equilibrium in changes

Revenue, country-sector:

$$\hat{R}_{is} R_{is} = \sum_j \frac{\hat{\lambda}_{ijs} \lambda_{ijs}}{1 + t'_{ijs}} \hat{X}_{js} X_{js}$$

Gross output:

$$\hat{Y}_i Y_i = \sum_s (1 - \eta_{is}) \hat{R}_{is} R_{is}$$

Consequences: Quantitative Model

Counterfactuals

$$\begin{aligned}
\hat{V}_j &= \frac{\widehat{Y_j + D_j +} T_j}{\hat{P}_j} \\
\hat{Z}_i &= \frac{\sum_s \gamma_{is} \hat{R}_{is} R_{is} / \hat{P}_{is} P_{is}}{\sum_s \gamma_{is} R_{is} / P_{is}} \\
\hat{W}_j &= \frac{\hat{V}_j}{1 + \delta(Z' - Z_0)}
\end{aligned}$$

Consequences: Quantitative Model

Counterfactuals:

1. Average tariff and NTB on all industries, each country
2. Average tariff and NTB on all industries, EU only
3. Carbon tariffs
4. Remove all tariffs and NTBs

Model-Based Estimates

Table 5—Effects of Setting Tariffs and NTBs to Mean, Model-Based Estimates

	Change in CO_2 Emissions (%) (1)	Change in Real Income (%) (2)	Change in CO_2 Intensity = (1) - (2) (3)	Climate benefits (4)	Social welfare (5)
Panel A. Global Total					
Global Total	-3.59%	0.65%	-4.24%	0.08%	0.57%
Panel B. By region					
Pacific Ocean	33.31%	1.02%	32.29%	—	—
Western Europe	23.33%	0.90%	22.43%	—	—
Eastern Europe	0.77%	0.99%	-0.22%	—	—
Latin America	-3.36%	0.74%	-4.10%	—	—
North America	-3.80%	0.26%	-4.06%	—	—
China	0.03%	0.22%	-0.19%	—	—
Southern Europe	54.67%	0.64%	54.03%	—	—
Northern Europe	26.96%	1.06%	25.90%	—	—
Indian Ocean	-5.15%	0.31%	-5.46%	—	—
Rest of World	-14.96%	0.93%	-15.89%	—	—

Model-Based Estimates

- ΔEmissions from coal
  - (1) ΔEmissions for domestic sales
    $\frac{\sum_i (\hat{R}_{ii,s}/\hat{P}_{ii,s}) Z_{ii,s}}{\sum_i Z_{ii,s}}$, weight $\left[\frac{\sum_i Z_{ii,s}}{\sum_i Z_{i,s}}\right]$
    - (2) ΔPrice index channel
      $\frac{\sum_i (1/\hat{P}_{ii,s}) Z_{ii,s}}{\sum_i Z_{ii,s}}$
    - (3) ΔNominal revenue channel
      $\frac{\sum_i (\hat{R}_{ii,s}) Z_{ii,s}}{\sum_i Z_{ii,s}} = \frac{\sum_i (\hat{\lambda}_{ii,s} \hat{X}_{is} / (\widehat{1+t_{ii,s}})) Z_{ii,s}}{\sum_i Z_{ii,s}}$
      - (4) ΔExpenditure share
        $\frac{\sum_i (\hat{\lambda}_{ii,s}) Z_{ii,s}}{\sum_i Z_{ii,s}}$
      - (5) ΔRevenue/expenditure gap
        $\frac{(1/(\widehat{1+t_{ii,s}})) Z_{ii,s}}{\sum_i Z_{ii,s}}$
      - (6) Δj×s expenditure
        $\frac{\sum_i (\hat{X}_{i,s}) Z_{ii,s}}{\sum_i Z_{ii,s}}$
        - (7) ΔFinal goods
          $\frac{\sum_i (\hat{X}^F_{i,s}) Z_{ii,s}}{\sum_i Z_{ii,s}}$
        - (8) ΔIntermediate goods
          $\frac{\sum_i (\hat{X}^I_{i,s}) Z_{ii,s}}{\sum_i Z_{ii,s}}$
  - (1) ΔEmissions for exports
    $\frac{\sum_{i,j \neq i} (\hat{R}_{ij,s}/\hat{P}_{ii,s}) Z_{ij,s}}{\sum_{i,j \neq i} Z_{ij,s}}$, weight $\left[\frac{\sum_{i,j \neq i} Z_{ij,s}}{\sum_i Z_{i,s}}\right]$

Model-Based Estimates

Appendix Table 9--Components of Changes in Fossil Fuel Consumption Due to Counterfactual Tariffs

	Total	Prices	Nominal Revenue						Baseline Emissions	Counterfactual Emissions
						Country×Sector Expenditure				
			Total	Expenditure Share	Revenue / Expenditure	Total	Final Goods	Intermediates		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel A: Oil										
Domestic Sales	-1.2%	-0.3%	-1.0%	1.3%	0.0%	-0.7%	0.6%	-0.7%	5.7	5.7
Exports	-8.2%	-0.6%	-6.4%	-7.5%	-1.5%	-0.8%	-0.7%	-0.7%	5.7	5.2
Panel B: Natural Gas										
Domestic Sales	-0.9%	-0.5%	-0.5%	0.0%	0.0%	-0.5%	0.6%	-0.6%	4.4	4.3
Exports	-12.8%	-0.5%	-11.0%	-11.6%	-1.5%	0.7%	-0.6%	0.8%	1.5	1.3
Panel C: Coal										
Domestic Sales	-4.7%	0.5%	-5.2%	-3.2%	0.0%	-2.1%	-0.5%	-2.1%	12.6	12.0
Exports	9.1%	0.3%	8.0%	8.0%	-1.1%	1.0%	-0.5%	1.1%	1.2	1.4

Model-Based Estimates

Appendix Table 8—Effects of Counterfactual Tariffs and NTBs on CO_2 Emissions and Welfare, Sensitivity Analysis

	CO_2 Emissions (1)	Real Income (2)	CO_2 Intensity = (1) - (2) (3)	Climate benefits (4)	Social welfare (5)
Panel A: Sensitivity Analysis for Main Counterfactual					
1. Baseline estimates	-3.59%	0.65%	-4.24%	0.08%	0.57%
2. Trade elasticities: Caliendo-Parro	-5.66%	0.55%	-6.21%	0.13%	0.42%
3. Larger energy elasticity	-2.53%	0.47%	-3.00%	0.06%	0.41%
3. Harmonize tariffs only	-1.75%	0.13%	-1.88%	0.04%	0.09%
4. Harmonize NTBs only	-2.26%	0.47%	-2.73%	0.05%	0.42%
5. Algorithm: trust-region	-3.59%	0.65%	-4.24%	0.08%	0.57%
6. Algorithm: Levenberg-Marquardt	-3.59%	0.65%	-4.24%	0.08%	0.57%
Panel B: Counterfactual sets EU tariffs and NTBs to mean					
Global total	-1.84%	0.25%	-2.10%	—	—
Panel C: Counterfactual sets tariffs and NTBs to mean of cleanest third of goods					
Global total	-5.09%	0.06%	-5.15%	0.11%	-0.05%
Panel D: Counterfactual sets tariffs and NTBs to mean of dirtiest third of goods					
Global total	-4.20%	1.13%	-5.33%	0.09%	1.04%
Panel E: All countries add a carbon tariff					
Global total	-2.52%	0.45%	-2.97%	0.06%	0.39%
Panel F: All Countries set tariffs and NTBs to zero					
Global total	1.31%	2.65%	-1.34%	-0.03%	2.68%

Conclusions

- Existing trade policy implicitly subsidizes CO_2 emissions
  - EU: trade policy is encouraging leakage, not preventing it
  - Aggregate subsidy to climate change $>$ \$500 billion/year
  - Policy reforms could decrease global CO_2, increase global GDP
- Main explanation: downstream industries have higher tariffs, lower CO_2 intensity
- Consequences
  - Trade policy negotiations consider climate change consequences of tariff escalation?

Agenda for today

- Stylized facts in pictures
- Quick overview of trade+environment
- Toy model
- Paper: Trade policy and climate change
- **Paper: Why is pollution declining?**

Why is Pollution from U.S. Manufacturing Declining?

The Roles of Trade, Regulation, Productivity, and Preferences

Joseph S. Shapiro[1] Reed Walker[2]

[1]Yale University and NBER

[2]UC Berkeley and NBER

Why are Manufacturing Pollution Emissions Declining?

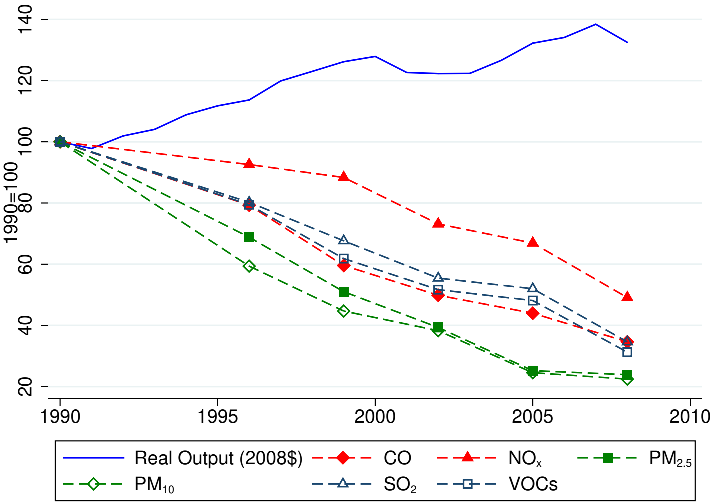


Figure: Pollution Emissions from U.S. Manufacturing

Why are Manufacturing Pollution Emissions Declining?

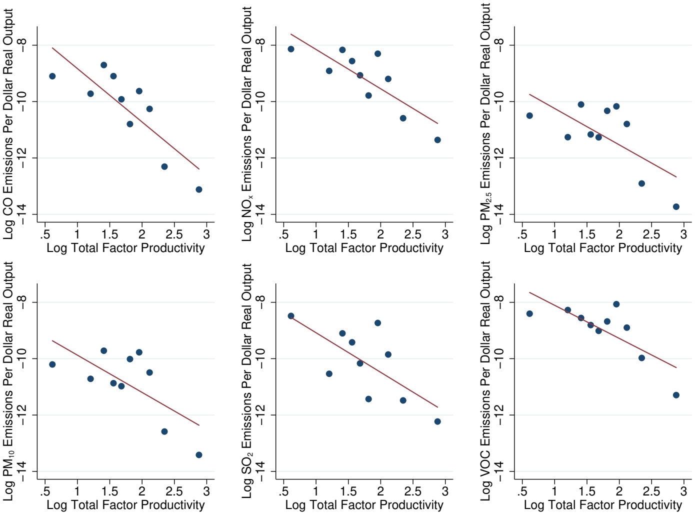
Potential explanations:

- Foreign competitiveness (Pierce and Schott 2012; Autor, Dorn, and Hanson 2013)
- Environmental regulation (Henderson 1996; Correia et al. 2013)
- Preferences (Levinson and O'Brien 2013)
- Productivity (Bloom et al. 2010, Martin 2011)

How distinguish empirically?

Why are Manufacturing Pollution Emissions Declining?

Plant-Level Evidence for Productivity:



Why are Manufacturing Pollution Emissions Declining?

This paper:

- Statistical decomposition
- Trade-environment model

Why are Manufacturing Pollution Emissions Declining?

This paper:

- Statistical decomposition
- Trade-environment model

Findings:

- Most pollution decrease is within narrowly-defined products
- Stringency of environmental regulation more than doubled 1990-2008
- Environmental regulation can account for large majority of decline in pollution emissions
  - Trade, productivity, preferences play smaller roles

Existing Research and Contributions

What is new here?

- Trade & Environment (Grossman and Krueger 1995; Antweiler, Copeland, and Taylor 2001; Copeland and Taylor 2003; Levinson 2009; Forslid, Okubo, and Ultveit-Moe 2011)
  - We structurally estimate a model of heterogeneous firms and endogenous pollution abatement
- Environmental regulation (Greenstone 2002; Ryan 2012; Walker 2013)
  - We measure the change in all local and national environmental regulation (shadow price of pollution)
- Gravity models (Eaton and Kortum 2002; Melitz 2003; Dekle, Eaton, and Kortum 2007; Chaney 2008; Eaton, Kortum, Neiman, and Romalis 2011; Hsieh and Ossa 2011; Arkolakis, Costinot, and Rodriguez-Clare 2012; Shapiro 2013)

Existing Research and Contributions

Important notes

- Model focuses on key decisions, abstracts from others.
  - Discuss fuel switching, induced innovation, others briefly at end.
- Model has arbitrary number of countries and sectors with productivity and trade costs as distinct shocks
  - Empirical implementation focuses on 2 countries, 17 sectors, and a combined “competitiveness” shock.

Overview

Overview

Statistical Decomposition

Trade-Environment Model

Data

Estimation and Results: Parameters and Shocks

Counterfactuals

Sensitivity

Conclusion

Statistical Decomposition: Background

Builds on Levinson (2009)

Standard decomposition:

- Scale: increase in real output
- Composition: shift in output from clean (e.g., furniture to steel)
- Technique: pollution per unit output

Goals:

- Establish what fraction of pollution reductions come from scale, composition, and technique effects
- Clarify what we learn from model's stronger assumptions

Statistical Decomposition: Methodology

Pollution summed across industries:

$$Z = \sum_s z_s = \sum_s x_s e_s = X \sum_s \kappa_s e_s$$

In vector notation,

$$Z = X\kappa' e$$

Totally differentiating gives

$$dZ = \underbrace{\kappa' e dX}_{\text{Scale}} + \underbrace{X e' d\kappa}_{\text{Composition}} + \underbrace{X\kappa' de}_{\text{Technique}}$$

Statistical Decomposition: Data

Data for statistical decomposition:

- National Emissions Inventory and Annual Survey of Manufactures (both 1990)
- Fuzzy string matching to create plant-level database
- Product-level information
- Apportion plant emissions to plant-product using product revenue shares

Statistical Decomposition: NO_x

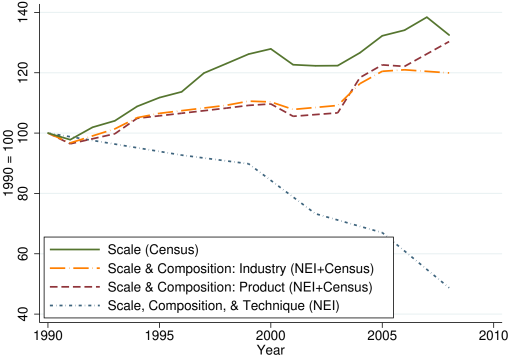
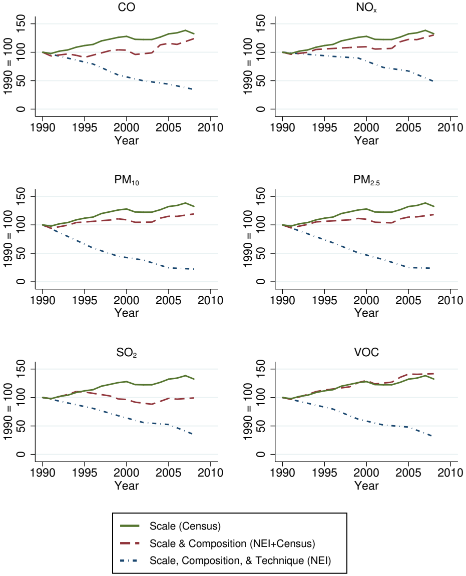


Figure: Nitrogen Oxides Emissions from U.S. Manufacturing: Scale, Composition, and Technique Effects

For ~1200 products defined in census microdata (e.g., “carbon wire rods”)

Statistical Decomposition: Criteria Pollutants



Overview

Trade-Environment Model

Assumption 1: Consumers have CES Preferences

- Multiple sectors

Assumption 2: Market structure is monopolistic competition

- Like Melitz (2003) but firms pay pollution taxes.
- Productivity distribution is Pareto

Assumption 3: Pollution is a second output which is taxed

- Like Copeland and Taylor (2003)
- Equivalently, production is Cobb-Douglas in factors and in pollution

Assumption 4: Competitive Equilibrium

- Lets us calculate counterfactual outcomes.

Trade-Environment Model: General Setup

- Representative agent
- One factor with inelastic supply ("labor")

Trade-Environment Model

Assumption 1: Consumers have CES Preferences

$$U_d = \prod_s \left(\left[\sum_o \int_{\omega \in \Omega_{o,s}} q_{od,s}(\omega)^{\frac{\sigma_s - 1}{\sigma_s}} d\omega \right]^{\frac{\sigma_s}{\sigma_s - 1}} \right)^{\beta_{d,s}} Z_d^{-\delta}$$

Multi-sector CES, pollution damages $Z_d^{-\delta}$

Pollution a pure externality

Assumption 2: Market structure is monopolistic competition

Assumption 3: Production is Cobb-Douglas in pollution and factors

Assumption 4: Competitive Equilibrium

Trade-Environment Model

Assumption 1: Consumers have CES Preferences

Assumption 2: Market structure is monopolistic competition

$$\pi_{o,s}(\varphi) = \sum_{d} \pi_{od,s}(\varphi) - w_o f_{o,s}^{e}$$

$$\begin{aligned}\pi_{od,s}(\varphi) &= p_{od,s}(\varphi)\, q_{od,s}(\varphi) - w_o l_{od,s}(\varphi)\, \tau_{od,s} \\ &\quad - t_o z_{od,s}(\varphi)\, \tau_{od,s} - w_d f_{od,s}\end{aligned}$$

$$G_{o,s}(\varphi) = 1 - (b_{o,s})^{\theta_s} / (\varphi)^{\theta_s}$$

Profits $\pi_{od,s}$, pollution $z_{od,s}$, pollution tax t_o, Pareto productivity $G_{o,s}$

Assumption 3: Production is Cobb-Douglas in pollution and factors

Assumption 4: Competitive Equilibrium

Trade-Environment Model

Assumption 1: Consumers have CES Preferences

Assumption 2: Market structure is monopolistic competition

Assumption 3: Pollution

$$z_{od,s} = (1-\xi)^{1/\alpha_s} \varphi l_{od,s}$$

All firms undertake some abatement.

Equivalent: production is Cobb-Douglas in pollution and factors; abatement sector; potential output

Assumption 4: Competitive Equilibrium

Trade-Environment Model

Assumption 1: Consumers have CES Preferences

Assumption 2: Market structure is monopolistic competition

Assumption 3: Production is Cobb-Douglas in pollution and in factors

Assumption 4: Competitive Equilibrium

Labor market clearing:

$$L_o = L_o^e + L_o^m + L_o^p$$

Utility maximization implies gravity

$$\lambda_{od,s} = \frac{M_{o,s}^e \left(\frac{w_o}{b_{o,s}}\right)^{-\theta_s} (\tau_{od,s})^{-\frac{\theta_s}{1-\alpha_s}} (f_{od,s})^{1-\frac{\theta_s}{(\sigma_s-1)(1-\alpha_s)}} (t_o)^{-\frac{\alpha_s\theta_s}{1-\alpha_s}}}{\sum_i M_{i,s}^e \left(\frac{w_i}{b_{i,s}}\right)^{-\theta_s} (\tau_{id,s})^{-\frac{\theta_s}{1-\alpha_s}} (f_{id,s})^{1-\frac{\theta_s}{(1-\alpha_s)(\sigma_s-1)}} (t_i)^{-\frac{\alpha_s\theta_s}{1-\alpha_s}}}$$

Trade-Environment Model: Equilibrium Conditions

Labor market clearing

Free entry condition + zero cutoff profit

In changes

Useful implication: change in pollution emissions

Trade-Environment Model: Equilibrium Conditions in Levels

Labor market clearing:

$$L_d = \frac{1}{\sum_s \frac{(\theta_s+1-\alpha_s)(\sigma_s-1)}{\sigma_s\theta_s}\beta_{d,s}} \sum_s M^e_{d,s} f^e_{d,s} \left(\theta_s + 1\right)$$

Free entry condition + zero cutoff profit

$$f^e_{o,s} \frac{\sigma_s \theta_s}{\left(\sigma_s - 1\right)\left(1 - \alpha_s\right)}$$

$$= \sum_d \frac{\left(w_o\right)^{-1}\left(w_o/b_{o,s}\right)^{-\theta_s}\left(\tau_{od,s}\right)^{-\frac{\theta_s}{1-\alpha_s}}\left(f_{od,s}\right)^{1-\frac{\theta_s}{(\sigma_s-1)(1-\alpha_s)}}\left(t_o\right)^{-\frac{\alpha_s\theta_s}{1-\alpha_s}}}{\sum_i M^e_{i,s}\left(w_i/b_{i,s}\right)^{-\theta_s}\left(\tau_{id,s}\right)^{-\frac{\theta_s}{1-\alpha_s}}\left(f_{id,s}\right)^{1-\frac{\theta_s}{(\sigma_s-1)(1-\alpha_s)}}\left(t_i\right)^{-\frac{\alpha_s\theta_s}{1-\alpha_s}}} E_{d,s}$$

Trade-Environment Model: Equilibrium Conditions in Changes

Methodology (Dekle, Eaton, and Kortum 2007): $\hat{x} \equiv x'/x$

Labor market clearing:

$$1 = \psi_o \sum_s \eta_s \hat{M}^e_{o,s}$$

Free entry condition + zero cutoff profit

$$\hat{w}_o =$$

$$\sum_d \frac{\zeta_{od,s} \left(\frac{\hat{w}_o}{\hat{b}_{o,s}}\right)^{-\theta_s} \left(\hat{\tau}_{od,s}\right)^{-\frac{\theta_s}{1-\alpha_s}} \left(\hat{f}_{od,s}\right)^{1-\frac{\theta_s}{(\sigma_s-1)(1-\alpha_s)}} \left(\hat{t}_{o,s}\right)^{-\frac{\alpha_s\theta_s}{1-\alpha_s}}}{\sum_i \lambda_{id,s} \hat{M}^e_{i,s} \left(\frac{\hat{w}_o}{\hat{b}_{o,s}}\right)^{-\theta_s} \left(\hat{\tau}_{od,s}\right)^{-\frac{\theta_s}{1-\alpha_s}} \left(\hat{f}_{od,s}\right)^{1-\frac{\theta_s}{(\sigma_s-1)(1-\alpha_s)}} \left(\hat{t}_{o,s}\right)^{-\frac{\alpha_s\theta_s}{1-\alpha_s}}} \hat{\beta}_{d,s} \hat{w}_d$$

Trade-Environment Model: Equilibrium Conditions in Changes

Change in pollution emissions

$$\hat{Z}_o = \sum_s \frac{\hat{M}^e_{o,s}}{\hat{w}_o \hat{t}_{o,s}} Z_{o,s}$$

Model Summary: Classes of Variables

Data ($X_{od,s}$, $Z_{o,s}$)

- Easy observed in year 1990

Parameters (σ_s, θ_s, α_s)

- Partial equilibrium relationships estimated from regressions

Shocks ($\hat{\tau}_{od,s}$, $\hat{f}_{od,s}$, $\hat{t}_{o,s}$, $\hat{b}_{o,s}$, $\hat{\beta}_{o,s}$)

- Policies that we choose to define a counterfactual.

Endogenous Variables ($\hat{w}_o$, $\hat{M}_{o,s}$)

- Determined by interaction of supply and demand to achieve a competitive equilibrium

Trade-Environment Model: Comparative Statics

Pollution per unit output ("pollution intensity"):

$$\frac{z_{od,s}}{q_{od,s}} = \frac{1}{\varphi^{1-\alpha_s}} \left(\frac{w_o}{t_{o,s}} \frac{\alpha_s}{1-\alpha_s} \right)^{1-\alpha_s}$$

Plant-level comparative statics. Pollution per unit output lower for

- More productive plants (φ)
- More stringent environmental regulation ($t_{o,s}$)

Overview

Data

Plant-level Microdata 1990 and 2005

- Annual Survey of Manufactures
  - Value of shipments, inventory-adjusted
  - Payments for factors and intermediates
  - Industry-year output and materials deflators
  - 60,000 plants/year

- US National Emissions Inventory
  - Plant-level pollution emissions from every US source
  - Main pollutants: CO, PM_{10}, $PM_{2.5}$, NO_x, SO_2, VOCs

- Pollution Abatement Costs and Expenditures Survey (PACE)
  - Reported expenditures on air pollution
  - Capital expenditures

Data

US industry-year aggregates

- National Emissions Inventory 1990, 1996, 1999, 2002, 2005, 2008

International country-industry-year aggregates: OECD STAN 1990-2008

- Gross output and international trade
- 26 countries, 17 industries (2-digit ISIC Rev. 3)
- Aggregate to 2 countries: US and Foreign

Data: Sectors

Code	Description	ISIC Rev. 3 Codes
1	Food, beverages, tobacco	15-16
2	Textiles, apparel, fur, leather	17-19
3	Wood products	20
4	Paper and publishing	21-22
5	Coke, refined petroleum, nuclear fuel	23
6	Chemicals	24
7	Rubber and plastics	25
8	Other non-metallic minerals	26
9	Basic metals	27
10	Fabricated metals	28
11	Machinery and equipment	29
12	Office, accounting, computing, and electrical machinery	30-31
13	Radio, television, communication equipment	32
14	Medical, precision, and optical, watches, clocks	33
15	Motor vehicles, trailers	34
16	Other transport equipment	35
17	Furniture, manufactures n.e.c., recycling	36-37

Overview

Statistical Decomposition

Trade-Environment Model

Data

Estimation and Results: Parameters and Shocks

Counterfactuals

Sensitivity

Conclusion

Estimates and Results: Parameters and Shocks

Parameters

- Pollution elasticity
- Elasticity of substitution
- Productivity dispersion

Counterfactual shocks:

- Foreign competitiveness
- Domestic competitiveness
- Environmental regulation
- Consumer preferences

Estimates and Results: Pollution Elasticity

Pollution elasticity α:

$$\frac{z}{q} = (1-\xi)^{(1-\alpha)/\alpha}$$

Estimating equation:

$$\Delta ln\Big(\frac{z_{i,t}}{q_{i,t}}\Big) = \frac{1-\alpha}{\alpha}\Delta ln(1-\xi_{i,t}) + \eta_t + \epsilon_{i,t}$$

Instrument $1-\xi$ **with nonattainment designations.**

- Rationale: reverse causality.

Estimates and Results: Pollution Elasticity

	CO	NO_x (O_3)	PM_{10}	$PM_{2.5}$	VOC (O_3)	Total (Any)
	Panel A: First Stage					
$\text{Nonattain}_{cp} \times \text{Polluter}_p$	-0.057***	-0.061***	-0.101	-0.126*	-0.063***	-0.058***
	(0.015)	(0.011)	(0.085)	(0.068)	(0.009)	(0.009)
	Panel B: Reduced Form					
$\text{Nonattain}_{cp} \times \text{Polluter}_p$	-7.386	-5.985	-9.474	-7.399	-7.812***	-5.346**
	(5.244)	(4.782)	(6.860)	(4.427)	(1.214)	(1.979)
	Panel C: Instrumental Variables					
Abatement Expenditure Ratio	130.030**	98.592	94.118	58.551	124.907***	91.604***
	(64.278)	(72.412)	(78.483)	(46.795)	(36.827)	(25.373)
N	≈3500	≈3500	≈3500	≈3500	≈3500	≈3500
First Stage F-Stat	14	30	1.4	3.4	52	42
	Panel D: Pollution Elasticity Parameter					
Pollution Elasticity (α)	0.008**	0.010	0.011	0.017	0.008***	0.011***
	(0.004)	(0.007)	(0.009)	(0.013)	(0.002)	(0.003)
County-NAICS FE	X	X	X	X	X	X

Estimates and Results: Macro Parameters

Elasticity of Substitution σ_s:

$$w_o L^p_{o,s} = (1-\alpha_s)\frac{\sigma_s - 1}{\sigma_s} X_{o,s}$$

Pareto shape parameter θ_s:

$$ln(Pr\{x > X_{i,s}\}) = \gamma_{0,s} + \gamma_{1,s} ln(X_{i,s}) + \epsilon_{i,s}$$

$\theta_s = \gamma_{1,s}(1-\sigma_s)$

Estimates and Results: Macro Parameters

Industry	Elasticity of Substitution (σ_s)	Pareto Shape Parameter (θ_s)	Shape Parameter Standard Error
Food, Beverages, Tobacco	3.79	3.89	(0.13)
Textiles, Apparel, Fur, Leather	4.87	4.80	(0.10)
Wood Products	5.94	6.20	(0.17)
Paper and Publishing	4.80	5.21	(0.10)
Coke, Refined Petroleum, Fuels	8.18	9.91	(1.67)
Chemicals	3.28	3.50	(0.08)
Rubber and Plastics	4.59	4.62	(0.08)
Other Non-metallic Minerals	3.66	4.05	(0.11)
Basic Metals	6.66	10.01	(0.50)
Fabricated Metals	4.77	4.80	(0.06)
Machinery and Equipment	4.25	4.19	(0.14)
Office, Computing, Electrical	5.24	5.32	(0.15)
Radio, Television, Communication	4.66	4.77	(0.23)
Medical, Precision, and Optical	2.89	2.86	(0.06)
Motor Vehicles, Trailers	5.62	5.60	(0.18)
Other Transport Equipment	3.88	3.87	(0.13)
Furniture, Other, Recycling	3.77	3.75	(0.03)
Mean Across Industries	4.76	5.14	(0.23)

Estimates and Results: Shocks

Need actual, historic values

- Parameters and data all we need to analyze counterfactuals
- But we want to analyze a specific counterfactual
  - What if one shock followed its actual, historic path but other shocks stayed fixed at 1990 values?
  - This requires knowing the actual, historic path of each shock
- How did trade costs, competitiveness, environmental regulation evolve 1990-2008?
- In principle, could use data on tariffs, shipping costs, announcements of new environmental regulation, etc. to investigate this
- Instead, we use the model itself to infer historic values

Estimates and Results: Shocks

Gravity equation in changes (1-sector version)

$$\hat{\lambda}_{od} = \hat{M}_o^e \left(\frac{\hat{w}_o}{\hat{b}_o} \right)^{-\theta} \left(\hat{\tau}_{od} \right)^{-\frac{\theta}{1-\alpha}} \left(\hat{f}_{od} \right)^{1-\frac{\theta}{(\sigma-1)(1-\alpha)}} \left(\hat{t}_o \right)^{-\frac{\alpha\theta}{1-\alpha}}$$

Invert it to define a shock:

$$\left(\hat{\tau}_{o,d} \right)^{-\frac{\theta}{1-\alpha}} \left(\hat{f}_{od} \right)^{1-\frac{\theta}{(\sigma-1)(1-\alpha)}} \left(\hat{b}_o \right)^{\theta} = \hat{\lambda}_{od} \frac{\left(\hat{w}_o \right)^{\theta}}{\hat{M}_o} \left(\hat{t}_o \right)^{\frac{\alpha\theta}{1-\alpha}}$$

Estimates and Results: Shocks

Definition of foreign competitiveness shock:

$$\hat{\Gamma}^*_{od,s} \equiv (1/\hat{b}_{o,s})^{-\theta_s} (\hat{\tau}_{od,s})^{-\theta_s/(1-\alpha_s)} (\hat{f}_{od,s})^{1-\theta_s/(\sigma_s-1)(1-\alpha_s)} * (\hat{t}_{o,s})^{-\alpha_s \theta_s/(1-\alpha_s)} \text{ for } o \neq U.S$$

Measurement of foreign competitiveness shock:

$$\hat{\Gamma}^*_{od,s} = \frac{\hat{\lambda}_{od,s}}{\hat{M}^e_{o,s} (\hat{w}_o)^{-\theta_s}} \left(\hat{P}_{d,s}\right)^{-\frac{\theta_s}{1-\alpha_s}} \left(\hat{\beta}_{d,s} \frac{\hat{w}_d w_d L_d - \widehat{NX_d} NX_d}{w_d L_d - NX_d}\right)^{1-\frac{\theta_s}{(\sigma_s-1)(1-\alpha_s)}}$$

Estimates and Results: Shocks

Definition of U.S. competitiveness shock:

$$\hat{\Gamma}^{*}_{od,s} \equiv \left(1/\hat{b}_{o,s}\right)^{-\theta_s} \left(\hat{\tau}_{od,s}\right)^{-\theta_s/(1-\alpha_s)} \left(\hat{f}_{od,s}\right)^{1-\theta_s/(\sigma_s-1)(1-\alpha_s)} \text{ for } o = U.S.$$

Measurement of U.S. competitiveness shock:

$$\hat{\Gamma}^{*}_{od,s} = \left(\hat{t}_{o,s}\right)^{\frac{\alpha_s\theta_s}{1-\alpha_s}} \frac{\hat{\lambda}_{od,s}}{\hat{M}^{e}_{o,s}\left(\hat{w}_o\right)^{-\theta_s}} \left(\hat{P}_{d,s}\right)^{-\frac{\theta_s}{1-\alpha_s}}$$

$$* \left(\hat{\beta}_{d,s} \frac{\hat{w}_d w_d L_d - \widehat{NX}_d NX_d}{w_d L_d - NX_d}\right)^{1-\frac{\theta_s}{(\sigma_s-1)(1-\alpha_s)}}$$

Estimates and Results: Shocks

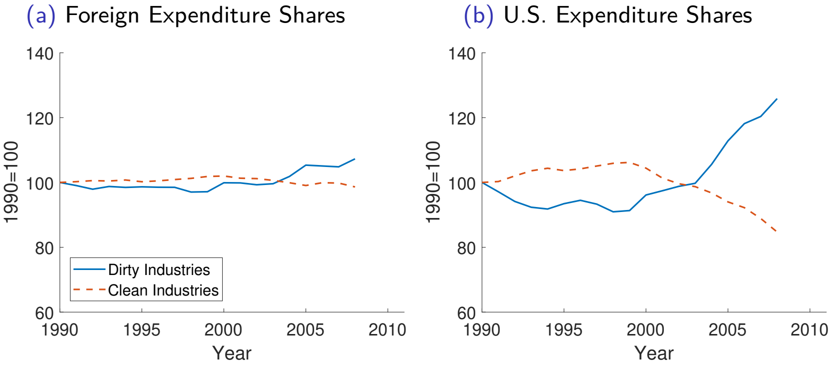
Preference Shock:

$$\hat{\beta}^*_{d,s} = \frac{\sum_o X'_{od,s} / \sum_{o,s} X'_{od,s}}{\sum_o X_{od,s} / \sum_{o,s} X_{od,s}}$$

Pollution regulation shock:

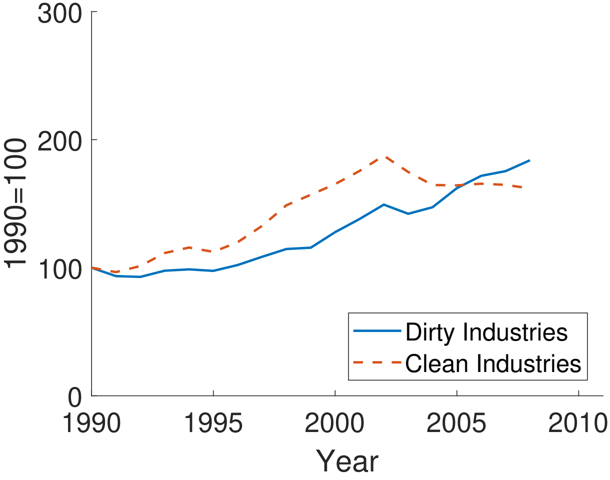
$$\hat{t}^*_{o,s} = \frac{\hat{w}_o \hat{M}^e_{o,s}}{\hat{Z}_{o,s}}$$

Estimates and Results: Historic Shocks, 1990-2008



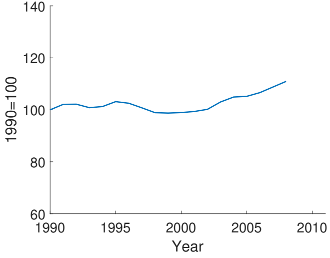
Estimates and Results: Historic Shocks, 1990-2008

Figure: Shocks to Implicit NO_x Pollution Tax

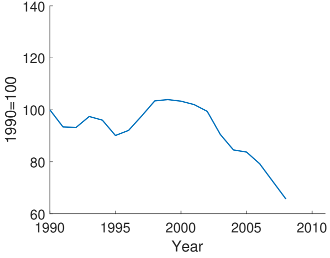


Estimates and Results: Endogenous Variables

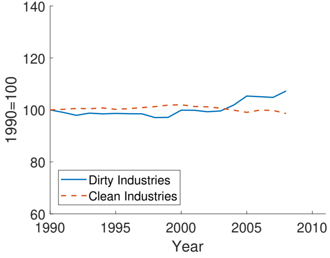
(a) Foreign Wages



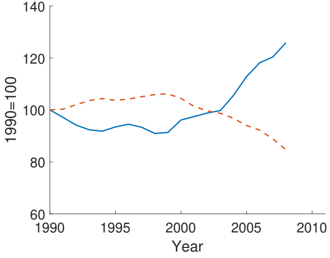
(b) U.S. Wages



(c) Foreign Firm Entry



(d) U.S. Firm Entry



Overview

Counterfactuals: Algorithm

Required data

- Data from 1990 ($X_{od,s}$, $Z_{o,s}$),
- Parameter vectors (α_s, σ_s, θ_s)

Three Step Algorithm

1. Define counterfactual: choose shocks $\{\hat{\Gamma}_{od,s}, \hat{t}_{o,s}, \hat{\beta}_{o,s}\}$
2. Find equilibrium: find changes to wages and firm entry ($\hat{w}_o$, $\hat{M}^e_{o,s}$) which make equilibrium conditions hold with equality
3. Recover U.S. pollution emissions, given results of first two steps

Counterfactuals: Algorithm

Counterfactuals we study

- One shock takes on historic values, others fixed at 1990 levels.

Example counterfactual

- Foreign competitiveness follows its historical path, other shocks fixed at 1990:

$$\{\hat{\Gamma}_{od,s}, \hat{t}_{o,s}, \hat{\beta}_{o,s}\} = \begin{cases} \{\hat{\Gamma}^*_{od,s}, 1, 1\} & \text{if } o \neq U.S. \\ \{1, 1, 1\} & \text{if } o = U.S. \end{cases}$$

Counterfactuals: Results

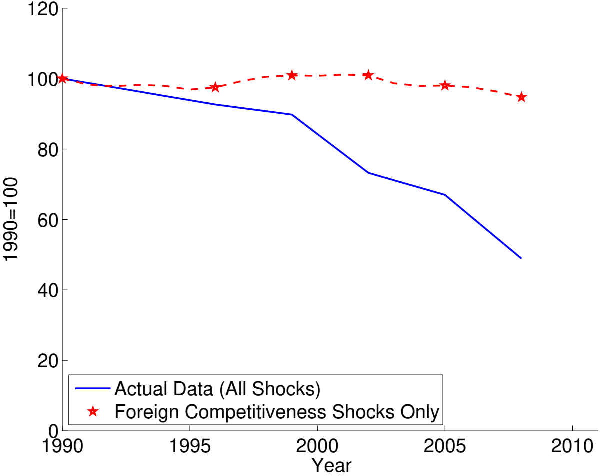


Figure: Counterfactual U.S. Manufacturing NOx Emissions, Foreign Competitiveness Shocks Only

Counterfactuals: Results

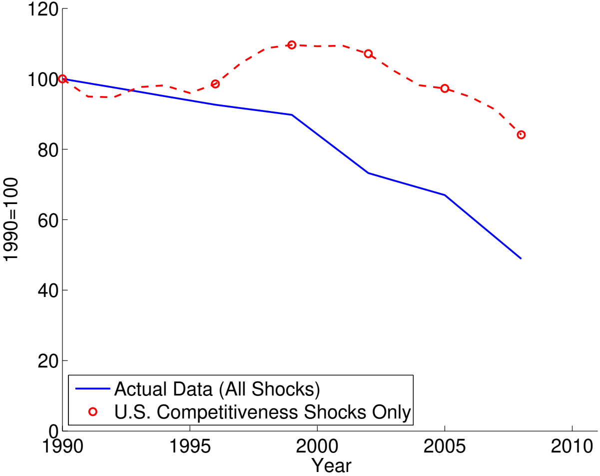


Figure: Counterfactual U.S. Manufacturing NOx Emissions, U.S. Competitiveness Shocks Only

Counterfactuals: Results

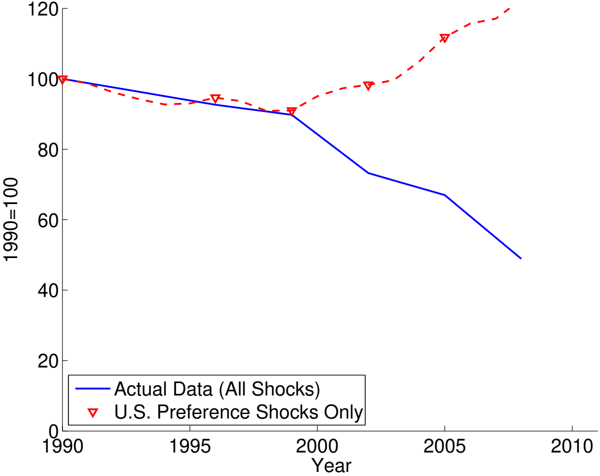


Figure: Counterfactual U.S. Manufacturing NOx Emissions, U.S. Preference Shocks Only

Counterfactuals: Results

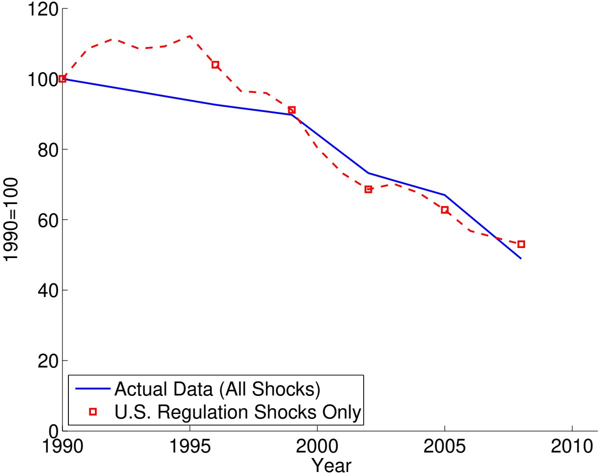


Figure: Counterfactual U.S. Manufacturing NOx Emissions, U.S. Regulation Shocks Only

Counterfactuals: Results, by Pollutant

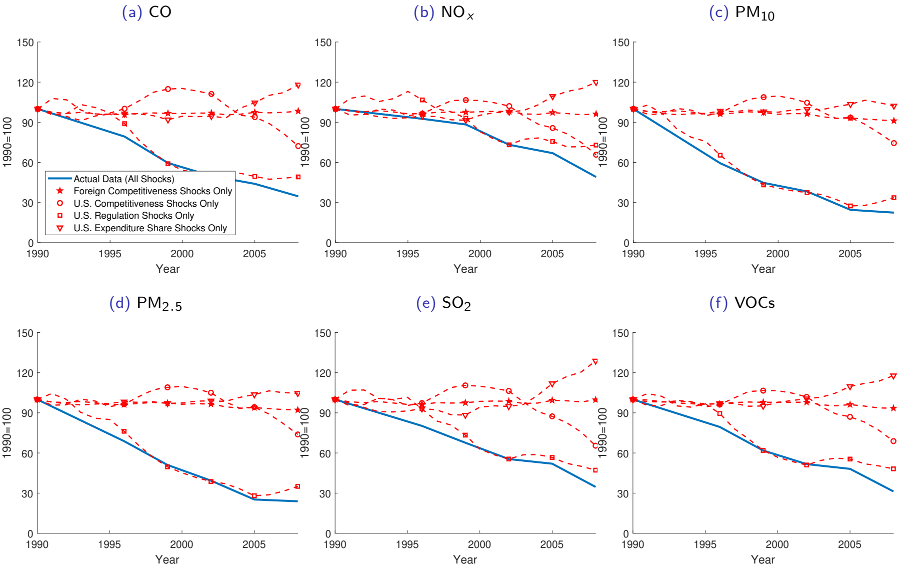


Figure: Counterfactual U.S. Manufacturing Pollution Emissions Under Subsets of Shocks, 1990-2008

Overview

Statistical Decomposition

Trade-Environment Model

Data

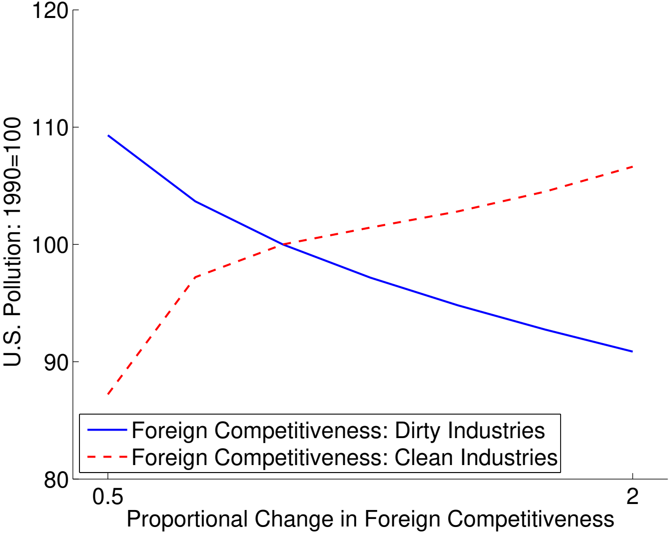
Estimation and Results: Parameters and Shocks

Counterfactuals

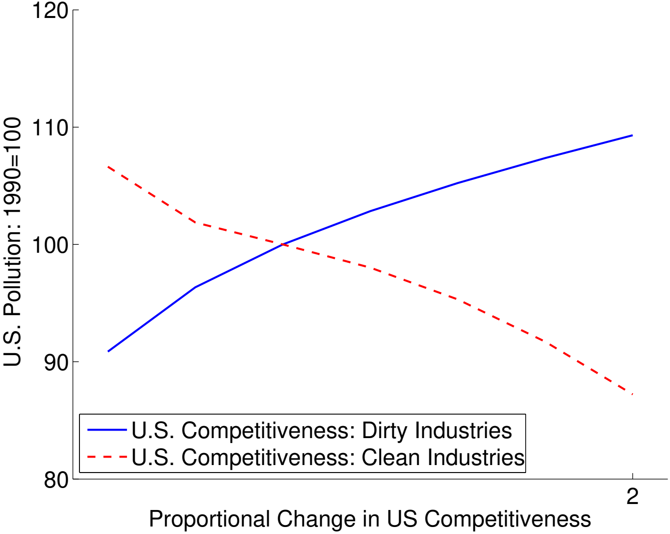
Sensitivity

Conclusion

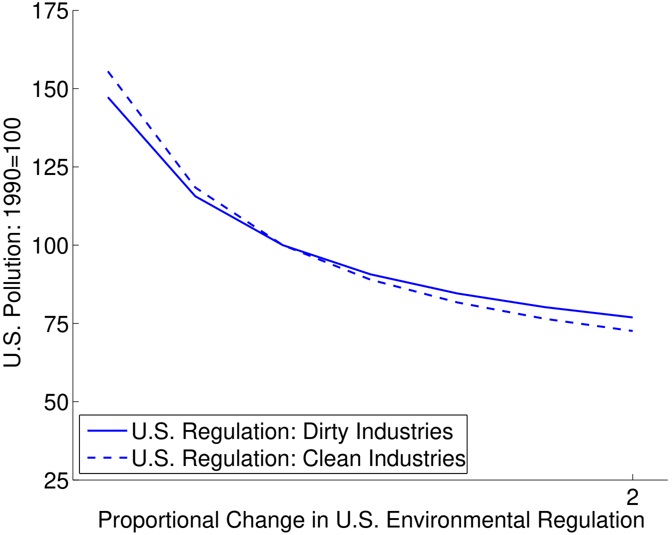
Sensitivity 1: Role of Other Shocks



Sensitivity 1: Role of Other Shocks

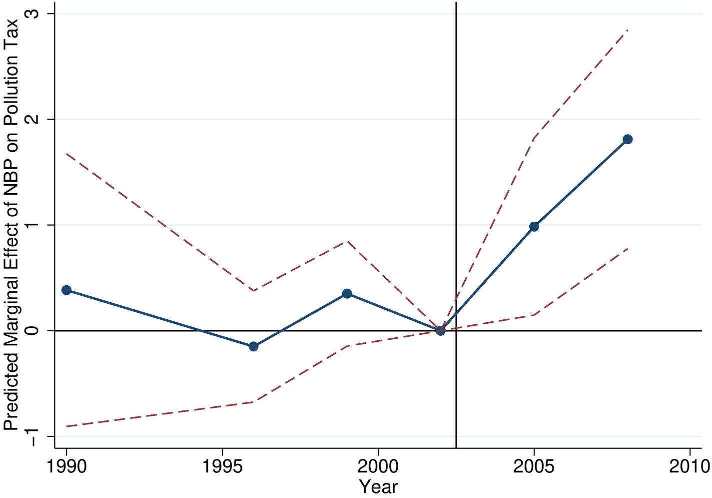


Sensitivity 1: Role of Other Shocks

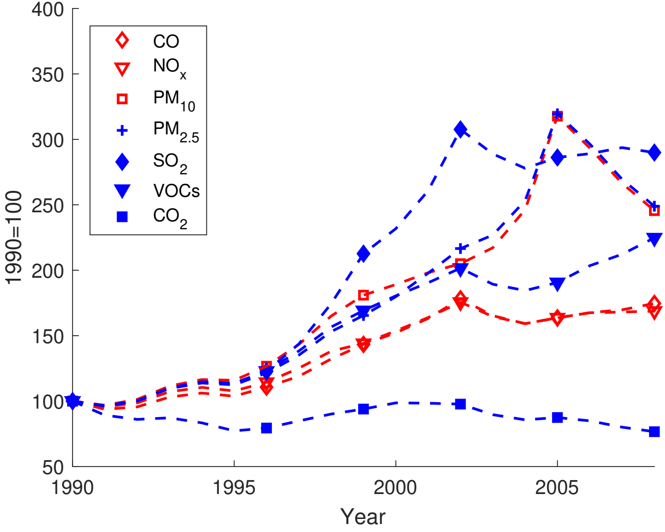


Sensitivity 2: Pollution Taxes and NO_x Budget Program

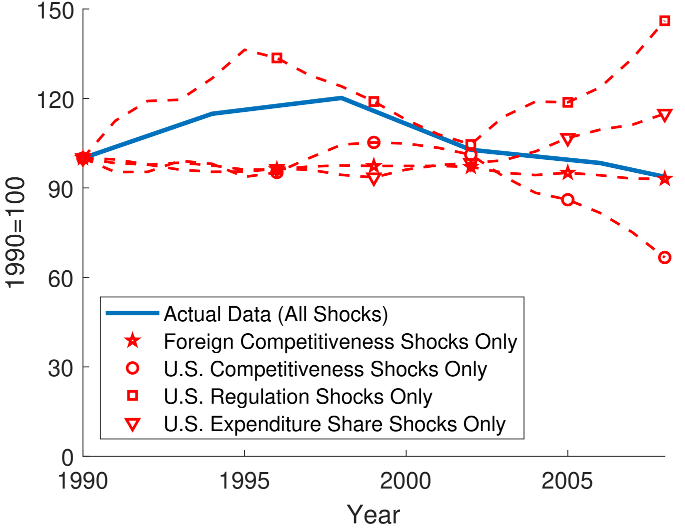
$\ln(\hat{t}_{jst}) = \beta_1 \left(1[NBP_s] \times 1[NBPIndustry_j] \times 1[Year > 2002]\right) + \eta_{st} + \gamma_{jt} + \psi_{js} + \epsilon_{jst}$



Sensitivity 3: Pollution Taxes, Air Pollution and CO_2



Sensitivity 3: Historic Pollution Decomposition for CO_2



Sensitivity: Other Considerations

Other considerations:

- Detail of industry categories
- Constant v. increasing returns to scale in pollution abatement
- Induced innovation, improvements in abatement technology

Overview

Statistical Decomposition

Trade-Environment Model

Data

Estimation and Results: Parameters and Shocks

Counterfactuals

Conclusions

Conclusions

Why are pollution emissions from manufacturing declining?

Open and important question.

- Methods from trade, application to environmental economics

Findings:

- Most of the decline is within narrowly-defined industries
- Pollution tax which rationalizes observed firm behavior has more than doubled since 1990
- Environmental regulation explains 75 percent or more of observed reductions in pollution emissions
  - Trade costs, productivity, preferences play smaller roles

Conclusions: general advice

- Look for a cluster
  - Questions, policies, research designs, data, theory
- First versus best
- Be ambitious / ask big questions (small questions are hard to answer too)
  - Can your parent/sibling/artist/architect friend see why it matters?
  - Nonlinear returns to paper quality
- Work in areas you care about
- Ideas come from many places
  - Conversations, news/magazine stories, journal articles, books, ...
  - Ask often: is there a paper here?
- Be your own RA / smarter not harder
- Structure your day/week/year around where/when you work well and happily