Why is Pollution from U.S. Manufacturing Declining?

The Roles of Trade, Regulation, Productivity, and Preferences

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Why are Manufacturing Pollution Emissions Declining?

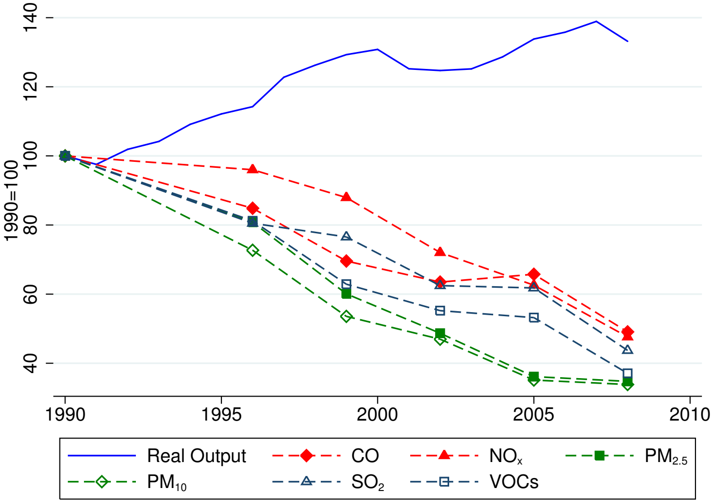


Figure: Pollution Emissions from U.S. Manufacturing

Why are Manufacturing Pollution Emissions Declining?

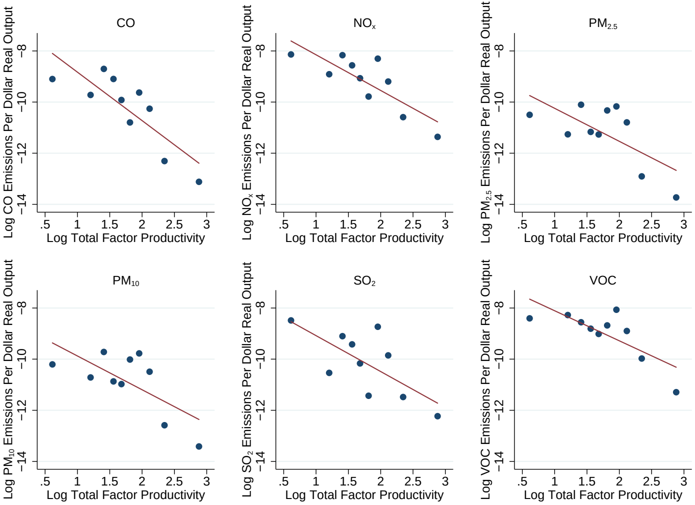
Potential explanations:

- 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?

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Findings:

- Most pollution decrease is within narrowly-defined products
- Stringency of environmental regulation more than doubled 1990-2008
- Environmental regulation explains 75% or more of decline in pollution emissions
  - Trade, productivity, preferences play limited role

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 2002; Dekle, Eaton, and Kortum 2007; Chaney 2008; Eaton, Kortum, Neiman, and Romalis 2011; Hsieh and Ossa 2011; Arkolakis, Costinot, and Rodriguez-Clare 2012; Eaton, Kortum, Neiman, and Romalis 2013; Shapiro 2013)

Overview

Statistical Decomposition

Trade-Environment Model

Data

Estimation and Results: Parameters and Shocks

Counterfactuals

Sensitivity

Conclusion

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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

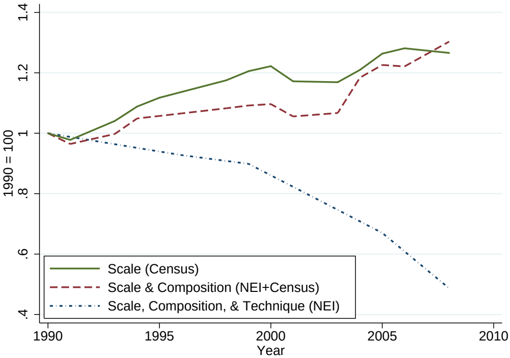
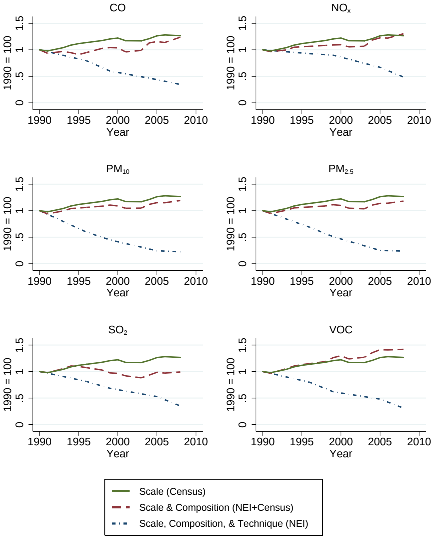


Figure: Nitrogen Oxides Emissions from U.S. Manufacturing: Scale, Composition, and Technique Effects

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

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

$$\pi_{od,s}(\varphi) = p_{od,s}(\varphi)\, q_{od,s}(\varphi) - w_o l_{od,s}(\varphi)\, \tau_{od,s} - t_o z_{od,s}(\varphi)\, \tau_{od,s} - w_o f_{od,s}$$

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

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:

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

Free entry condition + zero cutoff profit

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

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

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

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					
$Nonattain_{cp} \times Polluter_p$	-0.057*** (0.015)	-0.061*** (0.011)	-0.101 (0.085)	-0.126* (0.068)	-0.063*** (0.009)	-0.058*** (0.009)
	Panel B: Reduced Form					
$Nonattain_{cp} \times Polluter_p$	-7.386 (5.244)	-5.985 (4.782)	-9.474 (6.860)	-7.399 (4.427)	-7.812*** (1.214)	-5.346** (1.979)
	Panel C: Instrumental Variables					
Abatement Expenditure Ratio	130.030** (64.278)	98.592 (72.412)	94.118 (78.483)	58.551 (46.795)	124.907*** (36.827)	91.604*** (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** (0.004)	0.010 (0.007)	0.011 (0.009)	0.017 (0.013)	0.008*** (0.002)	0.011*** (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	Pareto Shape Parameter	Shape Parameter Standard Error
Food, Beverages, Tobacco	3.79	4.81	(0.13)
Textiles, Apparel, Fur, Leather	4.87	5.38	(0.10)
Wood Products	5.94	8.30	(0.17)
Paper and Publishing	4.80	4.29	(0.10)
Coke, Refined Petroleum, Fuels	8.18	17.52	(1.67)
Chemicals	3.28	4.13	(0.08)
Rubber and Plastics	4.59	5.02	(0.08)
Other Non-metallic Minerals	3.66	3.39	(0.11)
Basic Metals	6.66	9.72	(0.50)
Fabricated Metals	4.77	5.60	(0.06)
Machinery and Equipment	4.25	4.30	(0.14)
Office, Computing, Electrical	5.24	5.07	(0.15)
Radio, Television, Communication	4.66	4.13	(0.23)
Medical, Precision, and Optical	2.89	2.09	(0.06)
Motor Vehicles, Trailers	5.62	5.29	(0.18)
Other Transport Equipment	3.88	3.27	(0.13)
Furniture, Other, Recycling	3.77	4.77	(0.03)
Mean Across Industries	4.76	5.71	(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)

$$\hat{\lambda}_{od,s} = \hat{M}^e_{o,s} \left(\frac{\hat{w}_o}{\hat{b}_{o,s}} \right)^{-\theta_s} \left(\hat{\tau}_{od,s}\right)^{-\frac{\theta_s}{1-\alpha_s}} \left(\hat{f}_{od,s}\right)^{1-\frac{\theta_s}{(\sigma_s-1)(1-\alpha_s)}} \left(\hat{t}_{o,s}\right)^{-\frac{\alpha_s\theta_s}{1-\alpha_s}}$$

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:

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

Estimates and Results: Shocks

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:

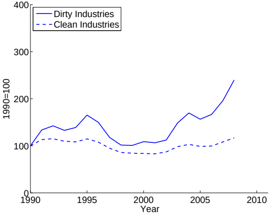
$$\hat{\beta}^{*}_{d,s} = \frac{\sum_o X'_{od,s} / \sum_{o,s} X'_{od,s}}{\sum_o X_{od,s} / \sum_{o,s} X_{od,s}}$$

Pollution regulation shock:

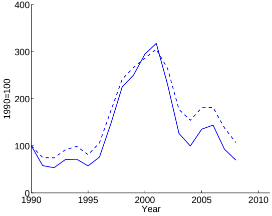
$$\hat{t}^{*}_{o,s} = \frac{\hat{w}_o \hat{M}^{e}_{o,s}}{\hat{Z}_{o,s}}$$

Estimates and Results: Historic Shocks, 1990-2008

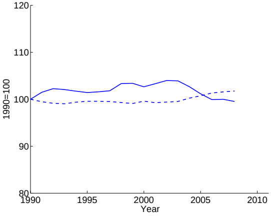
(a) Foreign Competitiveness



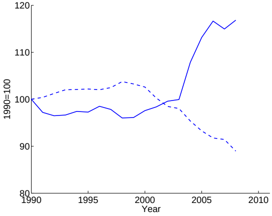
(b) U.S. Competitiveness



(c) Foreign Preferences

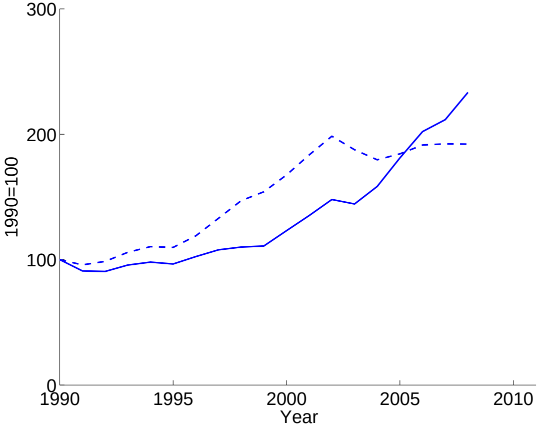


(d) U.S. Preferences



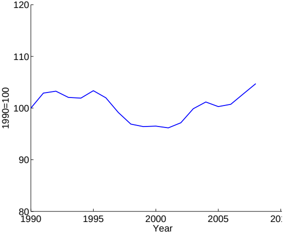
Estimates and Results: Historic Shocks, 1990-2008

Figure: U.S. Environmental Regulation

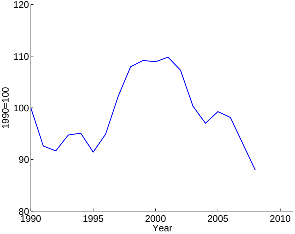


Estimates and Results: Endogenous Variables

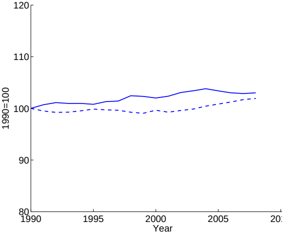
(a) Foreign Wages



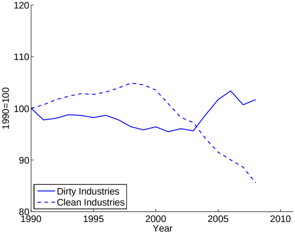
(b) U.S. Wages



(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

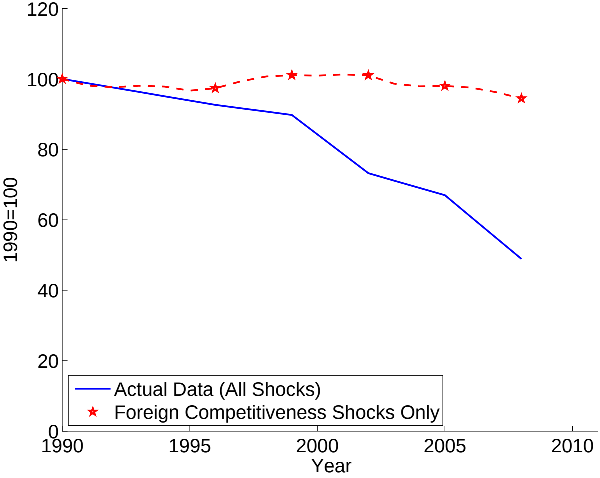


Figure: Counterfactual U.S. Manufacturing NOx Emissions, Foreign Competitiveness Shocks Only

Counterfactuals: Results

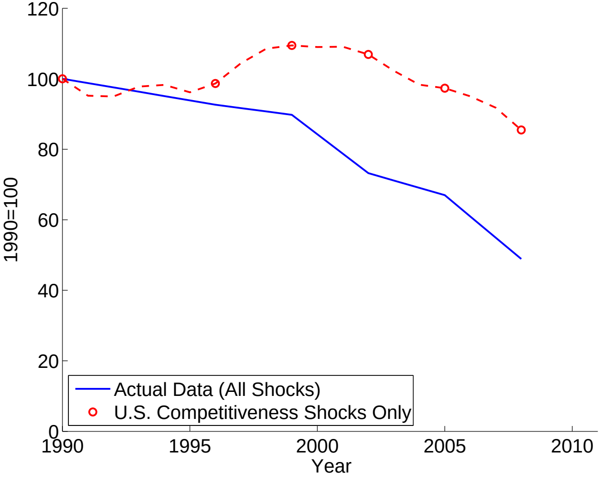


Figure: Counterfactual U.S. Manufacturing NOx Emissions, U.S. Competitiveness Shocks Only

Counterfactuals: Results

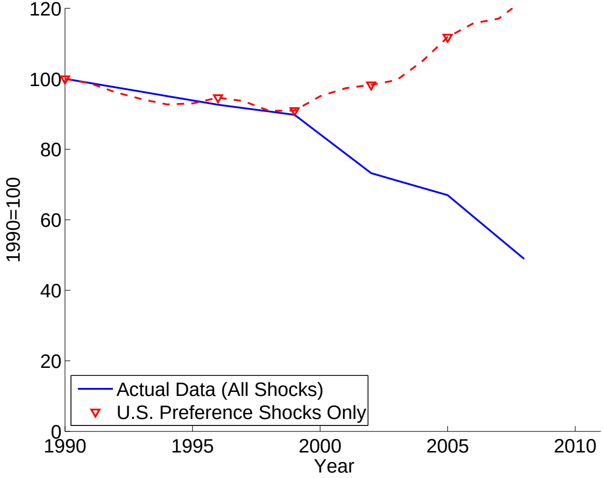


Figure: Counterfactual U.S. Manufacturing NOx Emissions, U.S. Preference Shocks Only

Counterfactuals: Results

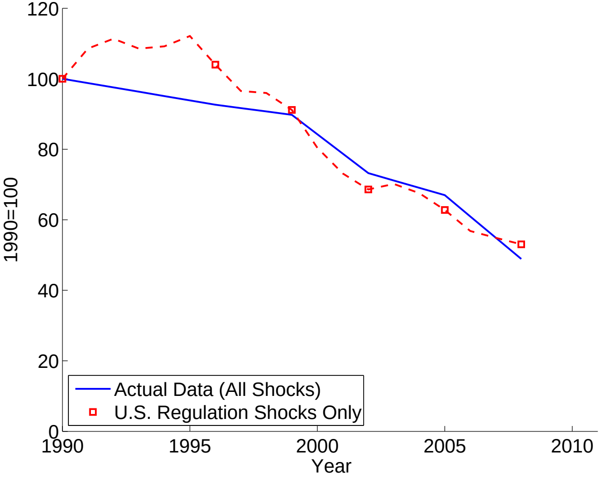


Figure: Counterfactual U.S. Manufacturing NOx Emissions, U.S. Regulation Shocks Only

Counterfactuals: Results, by Pollutant

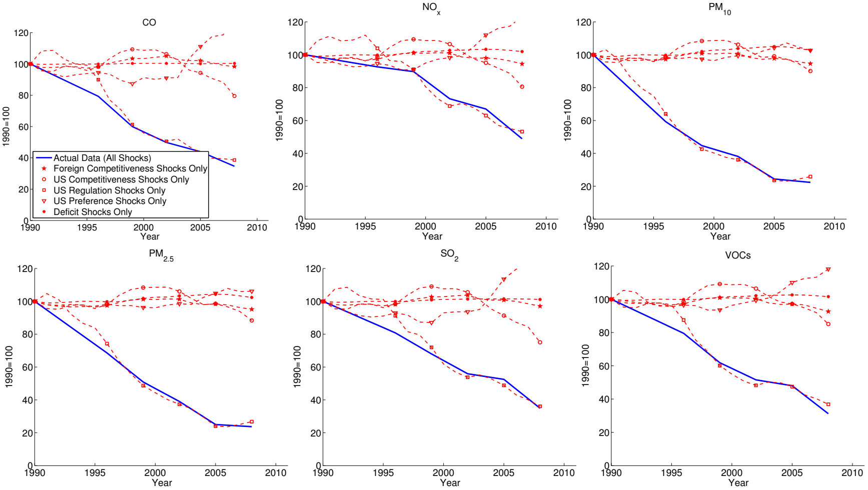
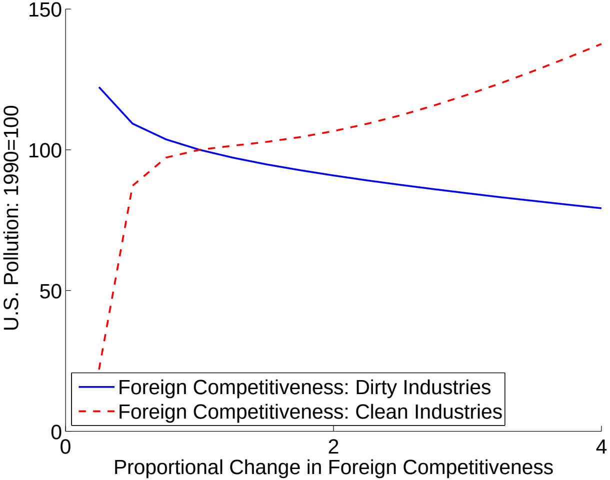


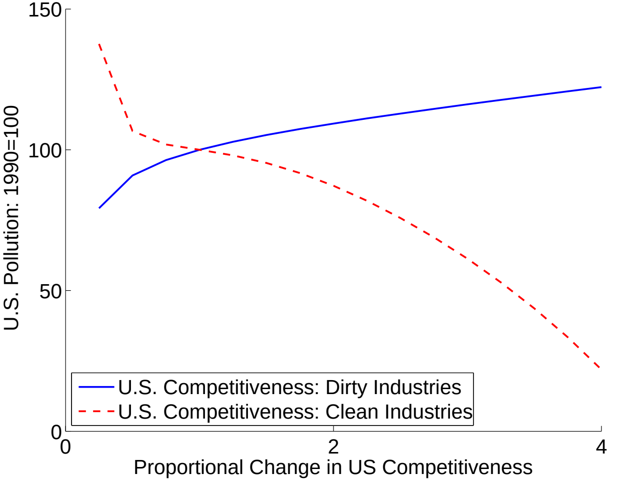
Figure: Counterfactual U.S. Manufacturing Pollution Emissions Under Subsets of Shocks, 1990-2008

Overview

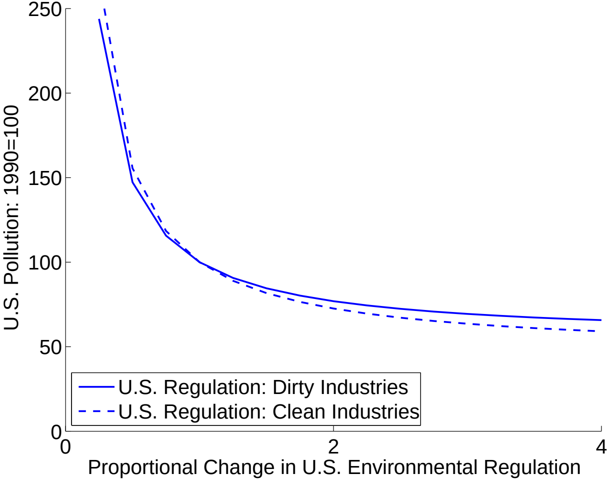
Sensitivity 1: Role of Other Shocks



Sensitivity 1: Role of Other Shocks

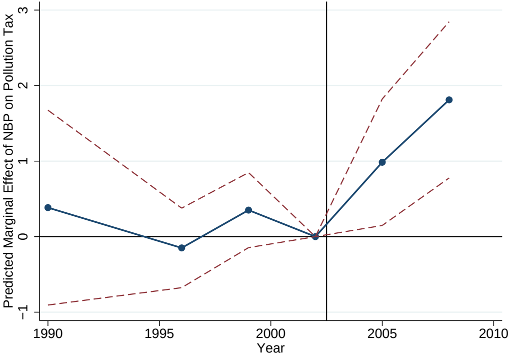


Sensitivity 1: Role of Other Shocks

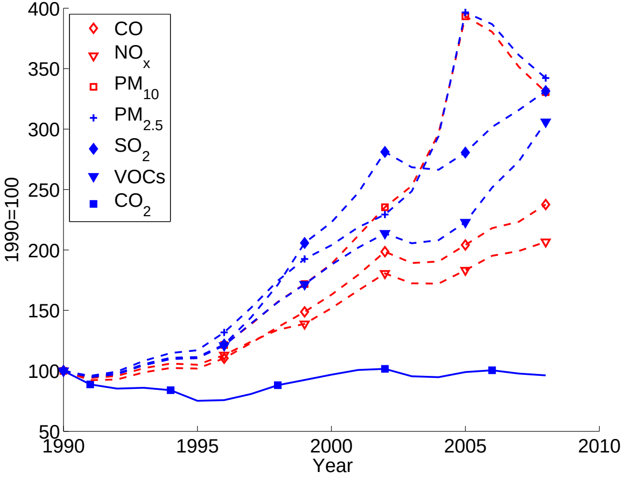


Sensitivity 2: Pollution Taxes and NOx Budget Trading Program

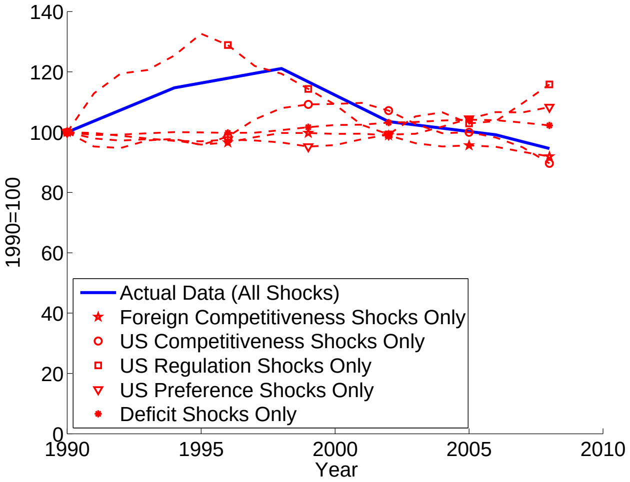
$$\ln(\hat{t}_{jst}) = \beta_1 \left(1[NBP_s] \times 1[NBPIndustry_j] \times 1[Year > 2002]\right) + \eta_{st} + \gamma_{jt} + \psi_{js} + \epsilon_{jst}$$



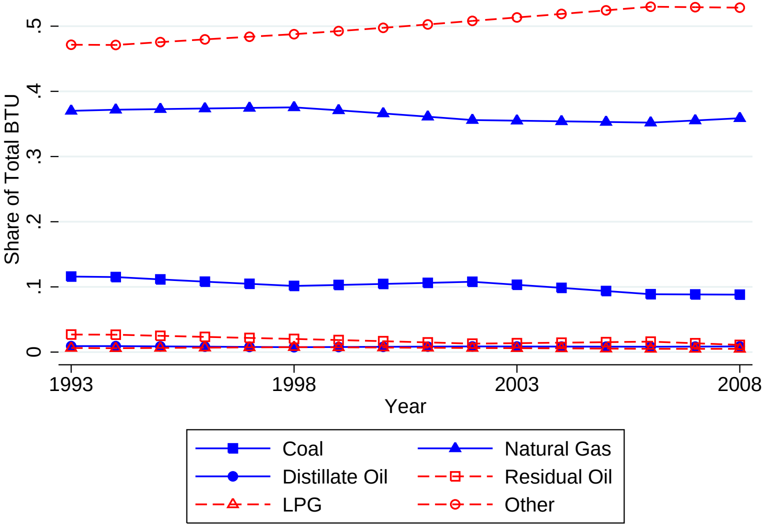
Sensitivity 3: Implicit Pollution Taxes for Air Pollution and for CO2

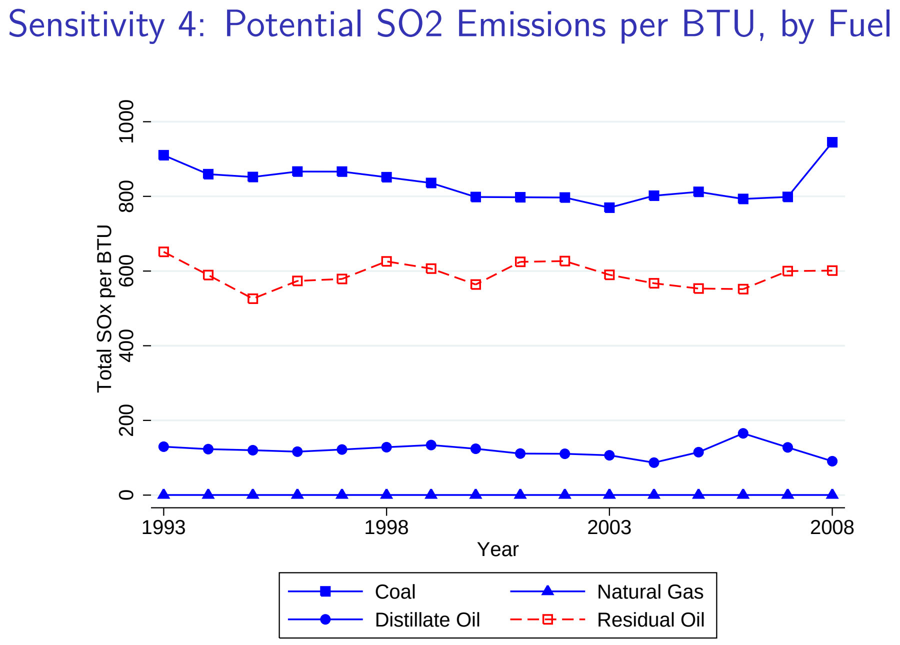


Sensitivity 3: Historic Pollution Decomposition for CO2

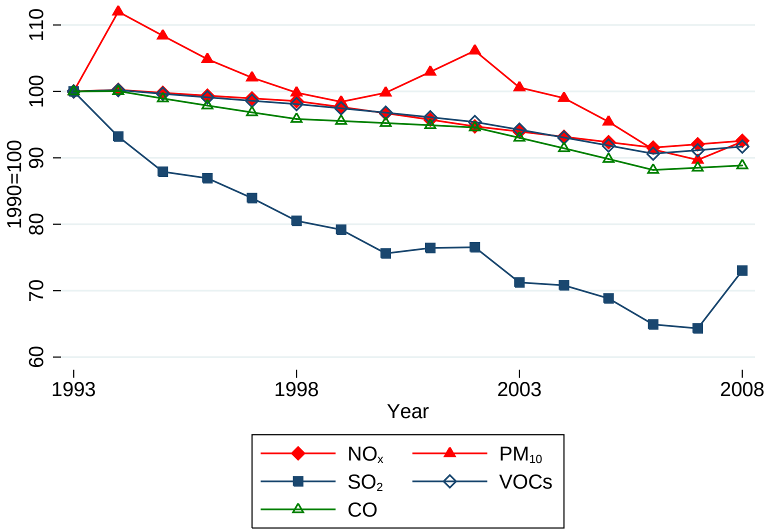


Sensitivity 4: Share of Heat Input from Each Fuel




Sensitivity 4: Potential SO2 Emissions per BTU, by Fuel
Total SOx per BTU
0
200
400
600
800
1000
1993
1998
2003
2008
Year
Coal
Natural Gas
Distillate Oil
Residual Oil

Sensitivity 4: Potential SO2 Emissions per BTU, by Fuel



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

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 of more of observed reductions in pollution emissions
  - Trade costs, productivity, preferences play little role

Topics for future work: apply these methods to energy efficiency; market power.

Trade-Environment Model: Price Index in Changes

Price index in changes:

$$\hat{P}_d = \prod_s (\hat{P}_{d,s})^{\beta_{d,s}}$$

$$\hat{P}_{d,s} = [(\hat{\beta}_{d,s})^{\frac{\theta_s}{(1-\alpha_s)(\sigma_s-1)}-1}$$

$$* \sum_o \lambda_{od,s} \hat{M}^e_{o,s} \left(\frac{\hat{w}_o}{\hat{b}_{o,s}}\right)^{-\theta_s} (\hat{\tau}_{od,s})^{-\frac{\theta_s}{1-\alpha_s}} (\hat{f}_{od,s})^{1-\frac{\theta_s}{(1-\alpha_s)(\sigma_s-1)}} (\hat{t}_o)^{-\frac{\alpha_s \theta_s}{1-\alpha_s}}]^{-\frac{1-\alpha_s}{\theta_s}}$$

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