Lecture 8: Trade and Pollution ECO 567A

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Syllabus

- Part I: Demand for Local Environmental Quality
  - Intro (Jan 10)
  - Demand I - Estimation (Jan 17)
  - Demand II - Sorting and Environmental Justice (Jan 24)
  - Amenities and Quant. Spatial Economic Models (Jan 31)
- Part II: Supply of Local Environmental Quality - Energy
  - Energy Production (Feb 7)
  - Energy Demand (Feb 14)
  - Energy Efficiency Innovation (Feb 21)
  - Trade and Pollution (March 7)
- Part III: Global Externalities
  - Climate Change (March 14)
- Final Exam March 19 9am - noon T5

Trade and Environment

Today

- How does International Trade impact pollution levels?
  - Pollution generated by manufacturing firms
- International Trade models
  - Workers are immobile (across countries)
  - Pollution is local and by product of production
  - Consumers can buy products on international market
  - Governments regulate local pollution optimally, taking prices as given

Today

- Copeland and Taylor (1994) Model
- Antweiler, Copeland and Taylor (2001) Empirical results
- Shapiro and Walker (2018) recent evidence

Copeland and Taylor (1994)

- Intuitively, free trade likely increase pollution (scale) but decreases emission intensity (endogenous regulation). Probably also relocates dirty industries to poor countries (composition).
- Can we study these effects with some more rigorous modeling?
- In particular:
  - In equilibrium, where is dirty production located?
  - What does free trade do to pollution?

Decomposing Pollution

- Pollution is given by

$$D = D(I, \tau, \tilde{z})$$

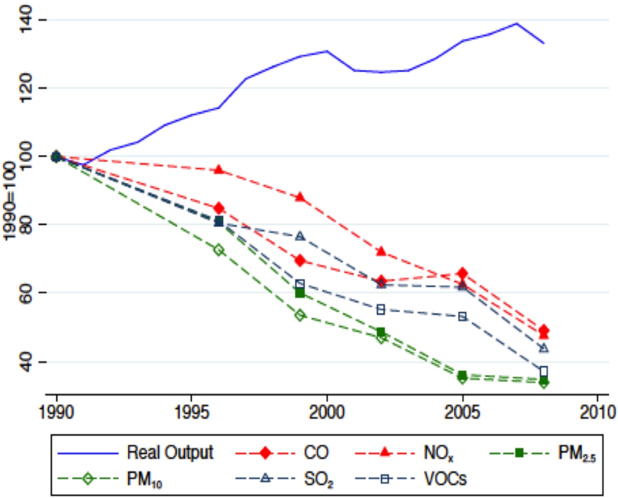
- Totally differentiating:

$$dD = \underbrace{\frac{\partial D}{\partial I} dI}_{scale} + \underbrace{\frac{\partial D}{\partial \tau} d\tau}_{Technique} + \underbrace{\frac{\partial D}{\partial \tilde{z}} d\tilde{z}}_{Composition}$$

- Or in percentage terms ($\hat{X} = \frac{dX}{X}$):

$$\hat{D} = \underbrace{\epsilon_{D,I} \hat{I}}_{scale} + \underbrace{\epsilon_{D,\tau} \hat{\tau}}_{Technique} + \underbrace{\epsilon_{D,\tilde{z}} \hat{\tilde{z}}}_{Composition}$$

Output and Emissions from Manufacturing in the US



Set up

- Two countries North and South (* denotes South)
- Country population $L = L^*$
- effective labor $\ell =$ A(h)L, with $h^* < h$
- Total effective labor $A(h)L > A(h^*)L$
- No transportation cost
- Consumption goods indexed by $z \in [0, 1]$
- Perfect competition

Production

- Output

$$
\begin{aligned}
y(\ell_y) &= \lambda^{\alpha(z)} \ell_y \\
d(\ell_a, \ell_y) &= \left[\frac{\lambda^{\alpha(z)} \ell_y}{[\ell_y + \ell_a]^{1-\alpha(z)}} \right]^{\frac{1}{\alpha(z)}}
\end{aligned}
$$

- with

$$
\alpha(z) \in [\underline{\alpha}, \bar{\alpha}], \;\; 0 < \underline{\alpha} < \bar{\alpha} < 1
$$

- Yields

$$
y = d^{\alpha(z)} \ell^{1-\alpha(z)}
$$

- effective labor ℓ costs w_e

- pollution d costs τ

details

Exogenous Pollution Taxes

- Cost minimization implies

$$\alpha(z) = \frac{\tau * d(z)}{p(z) * y(z)}$$

- Unit cost function

$$c(w, \tau; h, z) = \kappa(z)\tau^{\alpha(z)}\left[w/A(h)\right]^{1-\alpha(z)}$$

- order z such that

$$\alpha'(z) > 0$$

Exogenous Pollution Taxes

Suppose $\tau > \tau^*$

- Good z is produced in the North iff

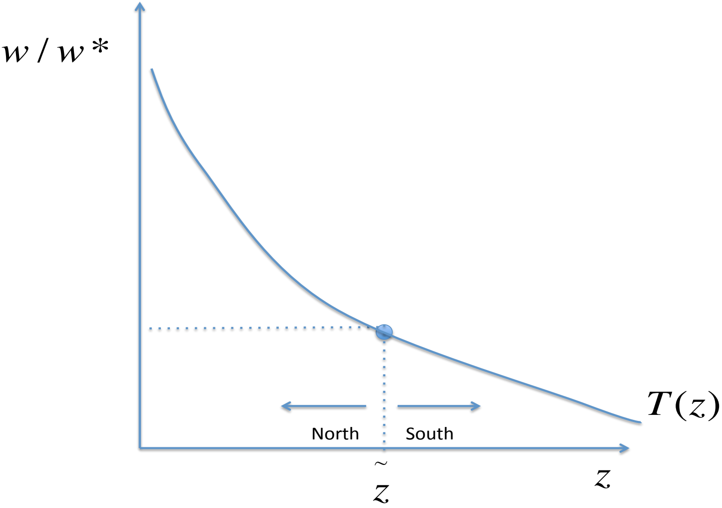
$$c(w, \tau; h, z) < c(w^*, \tau^*; h^*, z)$$

- Which holds iff

$$\omega \equiv \frac{w}{w^*} \leq \frac{A}{A^*} \left(\frac{\tau^*}{\tau} \right)^{\frac{\alpha(z)}{1-\alpha(z)}} \equiv T(z)$$

- With $\tau > \tau^*$ and $\alpha'(z) > 0 \implies T(z)$ decreasing in z

Exogenous Pollution Taxes



Exogenous Pollution Taxes

For given relative wage rate ω

- $T(z)$ determines cutoff $\tilde{z}$ such that
  - North produces all goods in range $[0, \tilde{z})$
  - South produces all goods in range $(\tilde{z}, 1]$

Endogenous Pollution Taxes

- Governments in North and South choose optimal τ to maximize National welfare
- Assuming output prices are exogenous

Demand

- Representative agent has utility

$$U = \int_0^1 b(z) \ln[x(z)] dz - \frac{\beta D^\gamma}{\gamma}$$

- Chooses $x(z)$ subject to income I/L
- Yields indirect utility

$$V = \int_0^1 b(z) \ln[b(z)] dz - \int_0^1 b(z) \ln[p(z)] dz + \ln(I/L) - \frac{\beta D^\gamma}{\gamma}$$

Optimal Tax

- Gov chooses τ equal to marginal damage of pollution:

$$\begin{aligned}\tau &= L * \frac{\partial V}{\partial D} * \frac{\partial \frac{I}{L}}{\partial V} \\ &= L * \beta D^{\gamma-1} * I/L \\ &= \beta D^{\gamma-1} I\end{aligned}$$

- Dividing optimal taxes:

$$\frac{\tau^*}{\tau} = \frac{I^*}{I}\left(\frac{D^*}{D}\right)^{\gamma-1}$$

Endogenous Pollution Taxes

- Define $\varphi(\tilde{z}) = \int_0^{\tilde{z}} b(z)dz$ the share of world expenditures on North goods and $\theta(\tilde{z}) = \int_0^{\tilde{z}} \alpha(z)b(z)dz$
- Then trade balance implies $I = \varphi(\tilde{z})(I + I^*)$
- Pollution in the North is given by

$$D = \int_0^{\tilde{z}} d(z)dz = \int_0^{\tilde{z}} \frac{\alpha(z)p(z)y(z)}{\tau}dz = \int_0^{\tilde{z}} \frac{\alpha(z)b(z)(I + I^*)}{\tau}dz$$

- which simplifies as

$$D = \frac{I}{\varphi}\frac{\theta}{\tau}$$

  using trade balance
- And plugging in optimal taxes

$$D = \left(\frac{\theta(\tilde{z})}{\beta\varphi(\tilde{z})}\right)^{1/\gamma} \quad , \quad D^* = \left(\frac{\theta^*(\tilde{z})}{\beta\varphi^*(\tilde{z})}\right)^{1/\gamma}$$

Endogenous Pollution Taxes

- And substituting back into $\frac{\tau^*}{\tau}$

$$\frac{\tau^*}{\tau} = \left(\frac{\theta^*(\tilde{z})}{\theta(\tilde{z})}\right)^{\frac{\gamma-1}{\gamma}} \left(\frac{\varphi^*(\tilde{z})}{\varphi(\tilde{z})}\right)^{\frac{1}{\gamma}} \equiv \psi(\tilde{z})$$

- From before

$$\omega \equiv \frac{w}{w^*} \leq \frac{A}{A^*}\left(\frac{\tau^*}{\tau}\right)^{\frac{\alpha(z)}{1-\alpha(z)}} \equiv T(z)$$

- Substituting in

$$\omega \equiv \frac{w}{w^*} \leq \frac{A}{A^*}\left(\psi(\tilde{z})\right)^{\frac{\alpha(\tilde{z})}{1-\alpha(\tilde{z})}} \equiv S(\tilde{z})$$

- $S(\tilde{z})$ decreasing in z

Balanced Trade

- Balanced trade implies

$$I = wL + \tau D \quad , \quad I^* = w^* L + \tau^* D^*$$

- Substituting pollution (considering just North)

$$I = wL + \frac{I\theta(\tilde{z})}{\varphi(\tilde{z})} \Longrightarrow I = \frac{\varphi(\tilde{z})wL}{\int_0^{\tilde{z}} b(z)(1-\alpha(z))dz}$$

- Dividing Incomes

$$\frac{I}{I^*} = \frac{\varphi(\tilde{z})}{1-\varphi(\tilde{z})}$$

- Substituting

$$\frac{w}{w^*} = \frac{\int_0^{\tilde{z}} b(z)(1-\alpha(z))dz}{\int_{\tilde{z}}^1 b(z)(1-\alpha(z))dz} \equiv B(\tilde{z})$$

Equilibrium

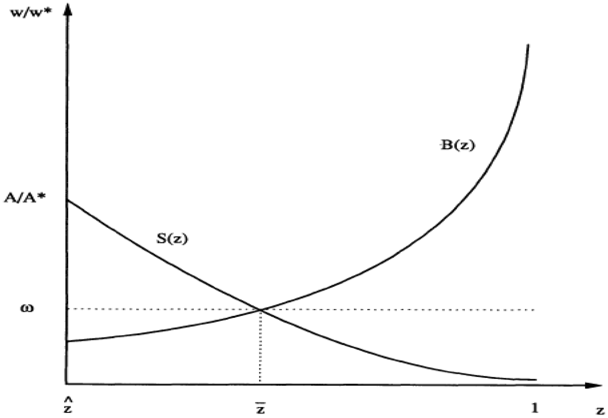


FIGURE II
Trading Equilibrium

Proposition 1

There exists an equilibrium with $\tau > \tau^*$ where North produces all goods $z \in [0, \widetilde{z})$ and South produces all goods $z \in (\widetilde{z}, 1]$ if and only if $A/A^* > \delta > 1$ where $\delta = B\left(\widehat{z}\right)$

Decomposing Pollution

- Pollution is given by

$$D = D(I, \tau, \tilde{z})$$

- Totally differentiating:

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Decomposing Pollution

- Evaluating the elasticities $D = I\frac{\theta}{\tau\varphi}$:

$$\frac{\partial D}{\partial I} = \frac{\theta}{\tau\varphi} > 0 \Longrightarrow \epsilon_{D,I} = 1$$

- Plugging in:

$$\hat{D} = \hat{I} - \hat{\tau} + (\hat{\theta} - \hat{\varphi})$$

- Note that

$$\tau = \beta D^{\gamma-1} I \Longrightarrow \hat{\tau} = (\gamma - 1)\hat{D} + \hat{I}$$

- Then substituting

$$\hat{D} = -\left[(\gamma - 1)/\gamma\right](\hat{\theta} - \hat{\varphi}) + (\hat{\theta} - \hat{\varphi}) = \frac{1}{\gamma}(\hat{\theta} - \hat{\varphi})$$

Results

1. The sign of the impact of pollution is determined by the sign of the composition effect

$$\hat{D} > 0 \iff \frac{1}{\gamma}(\hat{\theta} - \hat{\varphi}) > 0$$

2. A move from autarky to free trade causes

$$\frac{1}{\gamma}(\hat{\theta} - \hat{\varphi}) < 0 \quad , \quad \frac{1}{\gamma}(\hat{\theta}^* - \hat{\varphi}^*) > 0$$

   Hence, pollution goes down in the North and up in the South

3. Trade also increases worldwide pollution

Antweiler Copeland and Taylor (AER, 2001)

- In theory (Copeland and Taylor (1994)), composition dominates scale and technique , so changes in pollution are driven by changes in composition
- But the theoretical result is driven by functional forms. We don't know if all the assumptions hold.
- Also, what is a small "change in trade"? Need to model transportation costs/tariffs
- $\Longrightarrow$ Need to test empirically

Model

- Changes in pollution z can be decomposed as

$$\hat{z} = \pi_1 \hat{s}\left(\hat{\beta}\right) + \pi_2 (\widehat{K/L}) - \pi_3 \hat{I}\left(\hat{\beta}\right) + \pi_4 \hat{\beta}$$

  - s scale
  - (K/L) is capital to labor endowment ratio
  - I income
  - β trade frictions

- π_4 could be positive or negative depending on whether you export the dirty good

- Full trade effect $\frac{\partial z}{\partial \beta}\frac{\beta}{z} = \pi_1 \frac{\partial s}{\partial \beta}\frac{\beta}{s} - \pi_3 \frac{\partial I}{\partial \beta}\frac{\beta}{I} + \pi_4$

- Which under some assumption simplifies to

$$\frac{\partial z}{\partial \beta}\frac{\beta}{z} = (\pi_1 - \pi_3)\frac{\partial I}{\partial \beta}\frac{\beta}{I} + \pi_4$$

Data

Data

- z – $S0_2$ concentrations at individual monitor stations around the world
  - 2555 site-year observations
  - 290 pollution monitor sites
  - 43 countries
  - 108 cities
  - 1971-1996
- s – City-level GDP/km^2
- K/L – country-level capital to labor ratio (proxies for composition)
- I – country-level GNP/capita lagged (proxies for regulation)
- β – trade openness (X+M)/GDP   they call this TI

Estimation

Estimation

$$
\begin{aligned}
Z_{ijkt} &= \alpha_1 GDP/km_{jkt} + \alpha_2 KL_{kt} + \alpha_3 Inc_{kt} + \alpha_4 \psi_{kt} TI_{kt} \\
&+ \theta_{ijk} + \xi_t + \nu_{ijkt}
\end{aligned}
$$

- monitor i
- city j
- countries k
- year t

Identification

- Why not estimate in a cross section? I.e. why do ACT need θ_{ijk}?

- Why do ACT include ξ_t?

Identification

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- Suppose cities near the beach attract higher incomes. And being near the beach leads to lower pollution (wind disperses pollution). So Income will be correlated with lower pollution, independent of any regulation effect.
- Why do ACT include ξ_t?

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- Why do ACT include ξ_t?
- Time trends in productivity affect both GDP and emissions.

Regression Results

TABLE 1—ALTERNATIVE HYPOTHESES TESTS

Estimation method:	Random effects			Fixed effects		
Model specification:	A	B	C	A	B	C
Variable/column:	(1)	(2)	(3)	(4)	(5)	(6)
Intercept	−2.865***	−3.279***	−3.311***	−2.506***	−4.324***	−4.299***
City economic intensity GDP/km^2	0.042***	0.058***	0.070***	0.024*	0.058***	0.089*
(City economic intensity)^2/1,000			−0.244			−0.340
Capital abundance (K/L)	0.102**	0.293**	0.286*	0.165**	0.461**	0.437*
(K/L)^2		0.014	0.013		0.006	0.008
Lagged per capita income	−0.982***	−1.248***	−1.312***	−1.326***	−0.096	−0.228
(Income)^2		0.708***	0.669***		0.559***	0.578***
$(K/L) \times (I)$		−0.309***	−0.285***		−0.381***	−0.386***
Trade intensity TI = $(X+M)$/GDP	−0.915	−0.488	−0.510	−3.677***	−3.142**	−3.216**
TI × REL.K/L	−0.462	−1.952*	−1.828*	0.159	−2.252*	−2.121
TI × (REL.K/L)^2	0.018	−0.230	−0.248	−0.168	−0.123	−0.176
TI × REL.INC	0.470	1.056*	1.011*	2.128**	2.687***	2.614***
TI × (REL.INC)^2	0.118	−0.308*	−0.285*	−0.108	−0.595**	−0.584**
TI × (REL.K/L) × (REL.INC)	−0.165	0.870***	0.822***	−0.280	0.900**	0.924**
Suburban dummy	−0.299	−0.435*	−0.422*			
Rural dummy	−0.623	−0.674	−0.631			
Communist country (C.C.) dummy	0.312	−0.252	−0.257			
C.C. dummy × income	−0.283	4.569*	4.641*	1.170	9.621**	9.639**
C.C. dummy × (income)^2		−5.755**	−5.788**		−8.931***	−8.806**
Average temperature	−0.055***	−0.052***	−0.052***	−0.060*	−0.057*	−0.056*
Precipitation variation:	3.446	5.860	6.158	8.599	10.810*	10.716*
Helsinki Protocol:	−0.232*	−0.092	−0.114	−0.179	0.016	0.016
Observations	2,555	2,555	2,555	2,555	2,555	2,555
Groups	290	290	290	290	290	290
R^2	0.3395	0.3737	0.374	0.2483	0.131	0.1499
Log-likelihood	−2550	−2523	−2522	−3964	−3906	−3905
LR test/χ^2 (df)	55.596***	1.604		118.42***	2.035	
Hausman test/Wald χ^2 (df)	65.761**	15.158	53.789			
Scale elasticity	0.192***	0.265***	0.315***	0.112*	0.266***	0.398**
Composition elasticity	0.583**	0.948***	0.993***	0.945**	1.006**	0.975*
Technique elasticity	−0.905***	−1.577***	−1.577***	−1.222***	−1.153**	−1.266**
Trade intensity elasticity	−0.436***	−0.388***	−0.394***	−0.641***	−0.864***	−0.882***

Variation in Trade elasticity

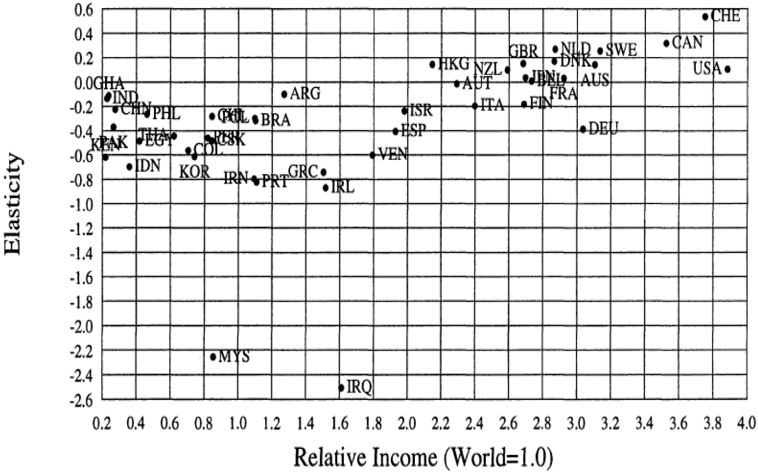


FIGURE 2. COUNTRY-SPECIFIC TRADE ELASTICITIES [MODEL B, RANDOM EFFECTS, CORRESPONDING TO TABLE 1 COLUMN (2)]

Full trade effect

- Full trade effect

$$\frac{\partial z}{\partial \beta}\frac{\beta}{z} = (\pi_1 - \pi_3)\frac{\partial I}{\partial \beta}\frac{\beta}{I} + \pi_4$$

- From the estimates $\pi_1 - \pi_3 = .112 - 1.222 = -0.9$ and $\pi_4 < 0$
- Hence, in this sample, an increase in income from reduced trade barriers lowers SO_2 concentrations overall

Identification

- Conditional θ_{ijk} and ξ_t, is the identification assumption likely to hold?

Identification

- Conditional θ_{ijk} and ξ_t, is the identification assumption likely to hold?

- Suppose new road construction raises GDP, but also raises pollution (more drivers). Emissions will correlate with GDP but not because of manufacturing output. Or to put it another way, if trade increases GDP by 1%, we should not expect emissions to increase by α_1.

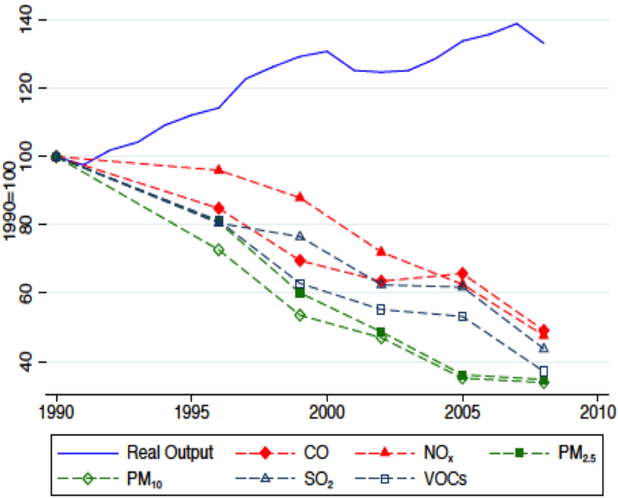
Limitations of Copeland and Taylor

- Pollution monitors are perhaps unreliable
- Identification assumption is unlikely to hold
- Ignores many important features
  - Firm-level heterogeneity in productivity
  - Changing preferences
  - Trends in productivity

Shapiro and Walker (2015)

- Firm-level production and pollution data
- Structural heterogeneous-firm trade model

Shapiro and Walker (2015)



Shapiro and Walker (2015)

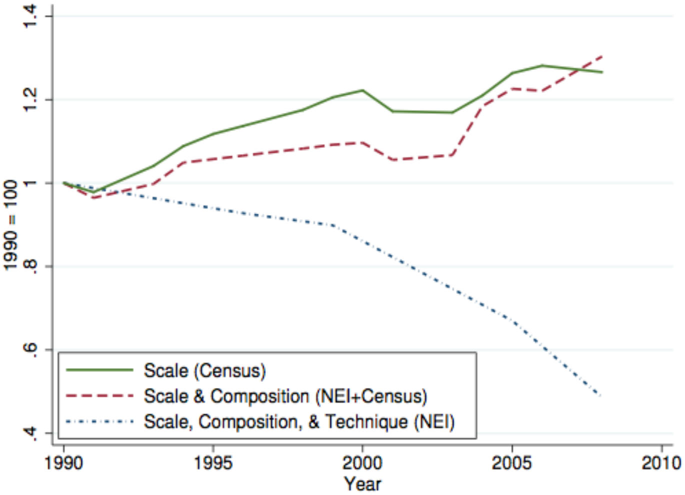
- Goal: disentangle the contribution of 4 factors in the reduction of US manufacturing emissions:
  1. changes in preferences (non-homothetic) toward cleaner goods
  2. trade (increased imports)
  3. regulation (especially CAAA)
  4. productivity growth: less inputs per output

Shapiro and Walker: Accounting decomposition

- Data on manufacturing emissions from 1990 to 2008
  - Annual Survey of Manufacturers (ASM): 1,440 product categories
  - Pollution data from EPA's National Emissions Inventory (NEI)
  - Output data from NBER-CES Manufacturing Industry Database: construct product-level output shares in each year
  - Emission intensity only for 1990, for which matching between NEI (emissions at the plant level) and ASM
- Same decomposition as Copeland and Taylor

$$Z = X\kappa' e$$

Shapiro and Walker: Results for NOx emissions



Strategy

- Solve a tarde model that accounts for endogenous abatement activity
- Back out historical "shocks" to regulation, competitiveness, and preferences
- Estimate key parameters of the model
- Replace historical shocks with counterfactual shocks, re-solve the equilibirum, and compute counterfactual emissions

Shapiro and Walker: Demand

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

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- ω indexes varieties – 1 firm $=$ 1 variety

Shapiro and Walker: Demand

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

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- $q_{od,s}(\omega)$ is consumption of variety ω produced in o and consumed in d in industry s

Shapiro and Walker: Demand

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- ω indexes varieties – 1 firm = 1 variety
- $q_{od,s}(\omega)$ is consumption of variety ω produced in o and consumed in d in industry s
- $\beta_{d,s}$ are preferences across sectors

Shapiro and Walker: Firms

- Copeland and Taylor's technology of abatement

$$q(\omega) = q(\varphi) = z^{\alpha_s} (\varphi l)^{1-\alpha_s}$$

Output and emissions $q = (1-\xi) l\varphi$ and $z = (1-\xi)^{\frac{1}{\alpha}} l\varphi$

- draw productivity φ from pareto distribution with CDF

$$G(\varphi) = 1 - \left(\frac{b_{o,s}}{\varphi}\right)^{\theta_s} \quad , \quad \varphi > b_{o,s}$$

- Firm pays $w_o f_o^e$ to learn φ

Shapiro and Walker: Equilibrium Conditions

- Zero expected profit

$$\int_{\varphi_D}^{\infty} \left(\sum_d \pi_{od}(\varphi) \right) dG(\varphi) = w_o f_o^e$$

- Labor market clearing

$$L = L^e + L^m + L^p$$

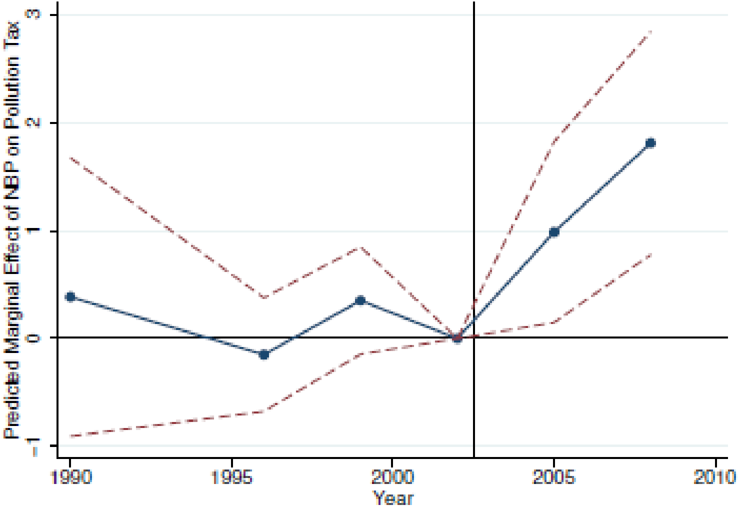
- $\implies$ These conditions pin down endogenous variables w_o, $M_{o,s}$

Shapiro and Walker: Shocks

- US Preferences $\beta_{US,s}$
- ROW Preferences $\beta_{ROW,s}$
- US Regulation $t_{US,s}$
- US Competitiveness $\Gamma_{US} = \Gamma(b_{o,s}, \tau_{od,s}, f_{od,s})$
- ROW Competitiveness $\Gamma_{ROW} = \Gamma(b_{o,s}, \tau_{od,s}, f_{od,s}, t_{o,s})$

Implied Environmental Taxes

- Euler implies $t_{o,s} Z_{o,s} = \alpha_s X_{o,s} \Longrightarrow \hat{t}^*_{o,s} = \frac{\hat{X}_{o,s}}{\hat{Z}_{o,s}}$



Estimating α

- Output and emissions $q = (1-\xi)l\varphi$ and $z = (1-\xi)^{\frac{1}{\alpha}} l\varphi$

- With plant-level data, construct balanced countyXIndustry pannel of 1990 and 2005, estimate

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

- Instrument for changes in the abatement cost share using changes in "non-attainment" status under CAAA

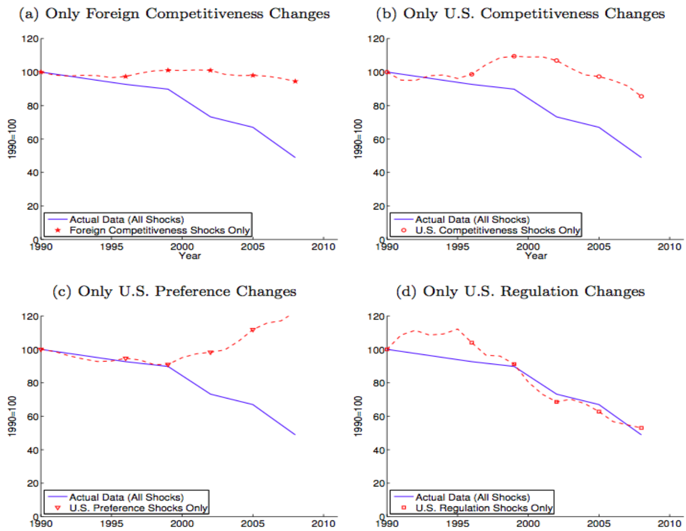
- $\alpha = 0.011$, and rescale for different sectors

Counterfactuals

- Use country x industry data from 1990 on production, trade, and US pollution emissions, and the parameter vectors for each industry
- Characterize the counterfactual scenario by choosing values for shocks (hypothetical or actual)
- Find the changes in wages and firm entry in each country x sector x year, using the equilibrium conditions
- Measure the resulting change in US pollution emissions

Main Result: Regulation matters

Figure 4: Counterfactual U.S. Manufacturing Emissions of NO_x Under Subsets of Shocks, 1990-2008



Conclusions from the literature

- With endogenous regulation, there is a strong technique effect which counteracts the scale effect. Composition effect is dominant.
- Empirically, "income" effect is very strong. Trade tends to lower emissions. (ACT, 2001)
- Emissions from manufacturing have declined. And this is due almost entirely to "technique".
- Regulation seems to be the driver rather than changes in competition, tastes, trade costs.

Abatement Function

back

- Output

$$\begin{aligned} y &= \lambda^{\alpha}\ell_y \\ d_0(y) &= \lambda^{1-\alpha}y = \lambda\ell_y \end{aligned}$$

- Abatement

$$Abate(\ell_a, d_0(y)) = d_0(y) - \left[\frac{\lambda^{\alpha-1}d_0(y)}{[d_0(y)/\lambda + \ell_a]^{1-\alpha}}\right]^{\frac{1}{\alpha}}$$

- Pollution

$$d(y, \ell_a) = \left[\frac{\lambda^{\alpha-1}d_0(y)}{[d_0(y)/\lambda + \ell_a]^{1-\alpha}}\right]^{\frac{1}{\alpha}} = \left[\frac{y}{[\ell_y + \ell_a]^{1-\alpha}}\right]^{\frac{1}{\alpha}}$$

- Output

$$y = d^{\alpha}\ell^{1-\alpha}$$