Evaluating the Cost of Energy and Environmental Policy

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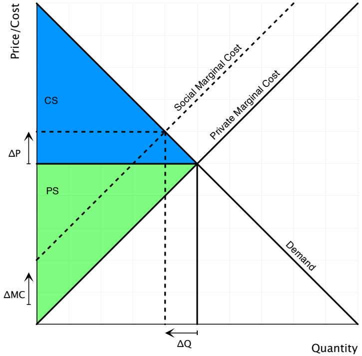
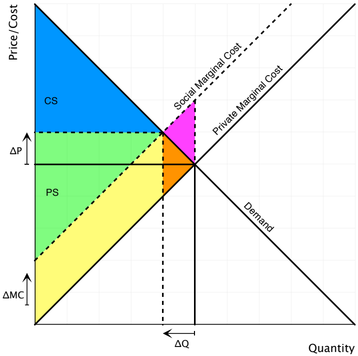
Fix Ideas: Welfare Analysis

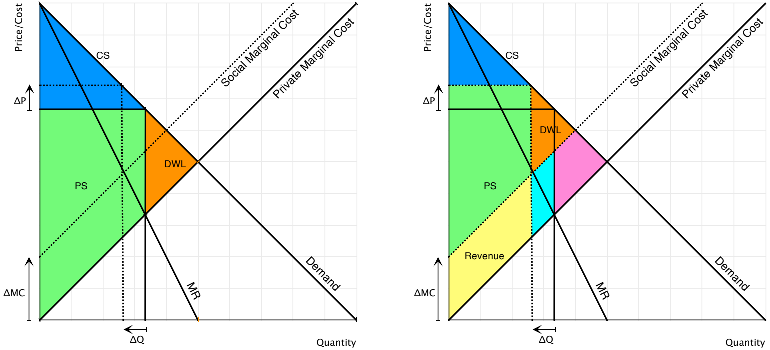




- **Welfare, Net Social Benefit**: Total Change in Welfare Due to Tax

$$\Delta W = dCS + dPS + dG + dE$$

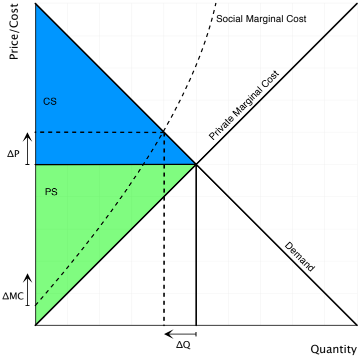
Fix Ideas: Welfare Analysis Differs with Market Structure

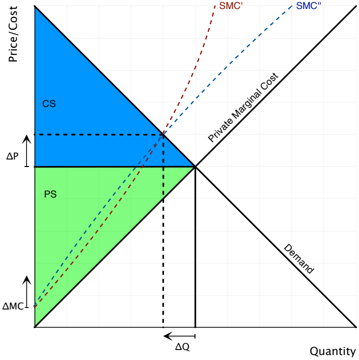


- **Welfare, Net Social Benefit**: Total Change in Welfare Due to Tax

$$\Delta W = dCS + dPS + dG + dE$$

Marginal Costs May Be Both Heterogeneous and/or Non-Linear.





Evaluating the Cost of Energy and Environmental Policy

Additional issues:

- Regulation may also affect the fixed costs of entry
  - Leading to changes in market structure
- Costs in one market may spill over to other markets
  - General equilibrium matters
- Pre-existing distortions and interaction effects
  - Theory of second best (i.e. anything goes)

Benchmarking Overall Costs

How Large Are Direct Compliance Costs?: Expenditures as fraction of GDP

Medium	Costs: EPA		Expenditures: EPA		Expenditures: BEA
Air	0.59		0.42		0.55
Water	0.88		0.68		0.70
Land and Other	0.63		0.83		0.42
Solid Waste		0.37		0.34	
Hazardous Waste		0.09		0.14	
LUST		0.07		0.16	
Superfund		0.04		0.08	
Other		0.07		0.11	
Total	2.11		1.93		1.67

Sources: EPA cost and expenditure estimates in 1986 dollars are from Tables 8-3A and 8-19A of U.S. Environmental Protection Agency, *Environmental Investments: The Cost of a Clean Environment* (Washington, D.C.: U.S. Environmental Protection Agency, November 1990). "Present implementation" is assumed, and costs are obtained by EPA from expenditures by annualizing investment outlays at a 7% discount rate. BEA expenditure estimates in 1987 dollars and the price indices to convert the EPA numbers to 1987 dollars were taken from Table 7 of G.L. Rutledge and M.L. Leonard, "Pollution Abatement and Control Expenditures, 1987-91," *Survey of Current Business* (May 1993): 55-62. GDP in 1987 dollars was taken from the 1993 *Economic Report of the President*.

Large Heterogeneity in Compliance Costs

Inter-Industry Differences in Private, Allocable Pollution Abatement Expenditures, 1990

Industry/Aggregate	Percent of Private, Non-farm GDP	Percent of Private, Non-farm Employment	Private, Allocable Pollution Abatement Expenditures: Percent of Total	Percent of GDP	Per employee (k$)
Paper & allied products	0.98	0.76	5.02	5.39	$3.589
Chemicals & allied products	2.17	1.18	11.22	5.43	5.157
Petroleum & coal products	0.77	0.17	7.20	9.79	22.472
Stone, clay, glass products	0.53	0.60	1.18	2.33	1.059
Primary metal industries	0.91	0.82	4.92	5.66	3.265
Transportation equipment	2.34	2.15	33.01	14.77	8.308
Electric utilities	3.37	0.69	9.24	2.87	7.252
Industries listed above	11.07	6.38	71.80	6.80	6.104
Manufacturing, mining, & electric utilities	26.32	21.08	82.71	3.29	2.126
Total private, non-farm	100.00	100.00	100.00	1.05	0.542

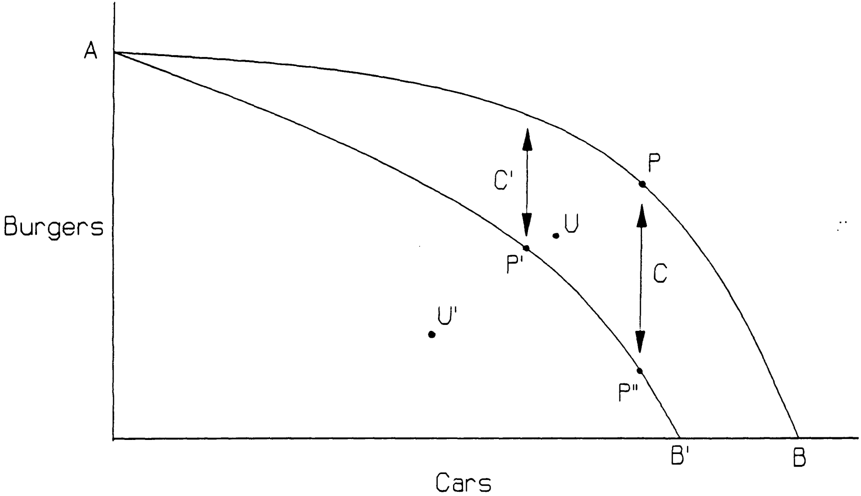
Sources: Pollution abatement capital spending and operating cost from *Pollution Abatement Costs and Expenditures, 1990*; electric utility operating costs and fuel differential, and total private business current and capital account spending for plant and equipment in 1990 dollars from unpublished BEA estimates; motor vehicle abatement costs (allocated to transportation equipment) and industry gross product originating data from the May, 1993 *Survey of Current Business*; employees from the March, 1991 *Employment and Earnings*. Spending per employee is in thousands of 1990 dollars. About 55 percent of BEA-estimated pollution abatement expenditures are covered; major unallocated expenditures include those related to sewer systems, regulation and monitoring, and research and development.

GDP is not a welfare measure

If regulation killed a sector, no compliance spending but huge economic losses (if goods valued by consumers)

Effects in Other Sectors...

- Protecting the Environment Lowers The Capacity to Meet Other Demands



Dynamic Considerations

Environmental regulation may inhibit investment in productive capital

- Requiring modifications or additions to new plant and equipment acts like a tax on new investment by reducing the amount of productive capacity acquired per dollar of investment.
  - This directly discourages investment in new capacity.

- Regulation that requires the addition of abatement and monitoring equipment to existing capacity tends to crowd out productive investment (and perhaps lower productivity)

Environmental regulation could discourage capacity expansion + slow economic growth.

How Do We Get from One Equilibrium to Another?

In the short run, shifts away from environmentally harmful production will lead to sectoral reallocation

- There may be costs associated with transitioning between pre/post regulatory equilibrium
- Labor reallocation costs
- Capital reallocation costs
- etc...

Effects of Economic or Social Regulations (Joskow & Rose)

1. The average price level and the structure of prices
2. The static costs of production, including:
   1. input distortions,
   2. X-inefficiency,
   3. direct regulatory costs, and
   4. input prices paid.
3. Dynamic efficiency, including rate/direction of innovation/productivity.
4. Product quality and variety.
5. Distribution of income and rents, including:
   1. profitability of regulated firms,
   2. rent-sharing with factors of production,
   3. income transfers among customer groups, and
   4. income transfers among producer groups.
6. Transition Costs: capital and/or labor

How to Estimate/Measure Social Cost of Regulation?

Three Main Approaches

1. (Computable) General Equilibrium Models + Counterfactuals
2. "Ground-up" IO Models of a single sector + Counterfactuals
3. Program Evaluation Methods (i.e. ex post analysis)

How Well Do Different Methods Capture Entirety of Compliance Costs?

Computable General Equilibrium Models

Used extensively by government agencies, think tanks, and consultancies to forecast effects of future policies

- Not a tremendous amount of recent innovation from the academic community
- Strong identifying assumptions + lack of transparency
- Basis for analysis stems from basic I/O table (Leontief), but models now allow for equilibrium responses/feedback based on demand / elasticities of substitution across sectors

Jorgenson and Wilcoxen (1990)

- Production sector is central to the supply side of the model (35 sectors) while household sector forms the core of the demand side (representative agent)
- Market-clearing conditions determine supplies and demands for all commodities along with the corresponding prices.
- Intertemporal equilibrium requires that market-clearing conditions are satisfied for each commodity at each point of time.
- Also model government, and exports, imports!

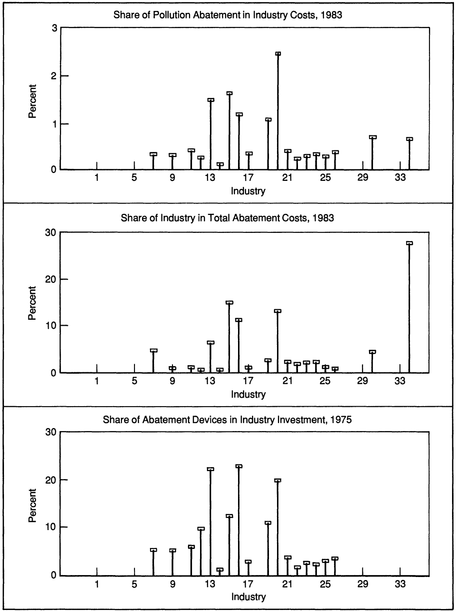
Pollution Abatement: Consider three counterfactuals

- Costs of pollution control, pollution control investment, and compliance with motor vehicle emissions standards

Headline Findings: Mandated abatement costs reduce the average growth rate of real GNP by about 0.2 percentage points per year (between 1974-1985)

- much of the adverse effects due to an increase in the cost of capital

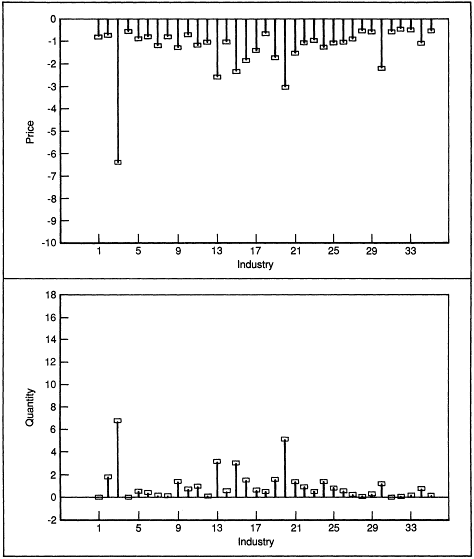
Jorgenson and Wilcoxen (1990)



Jorgenson and Wilcoxen (1990)

FIGURE 4

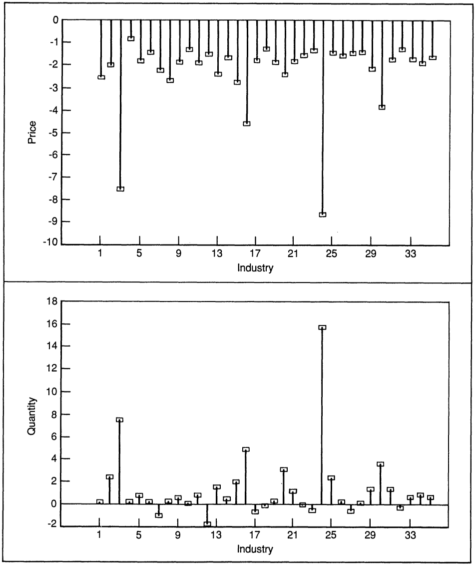
THE EFFECTS OF REMOVING ABATEMENT COSTS ON INDUSTRIES



Jorgenson and Wilcoxen (1990)

FIGURE 10

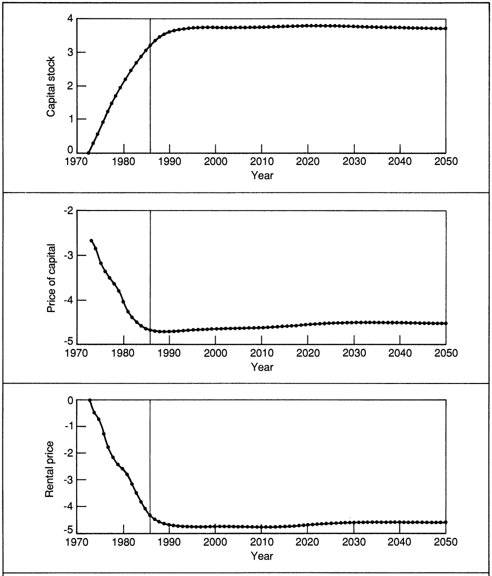
THE EFFECTS OF REMOVING ALL ENVIRONMENTAL REGULATION ON INDUSTRIES



Jorgenson and Wilcoxen (1990)

FIGURE 11

THE DYNAMIC EFFECTS OF REMOVING ALL ENVIRONMENTAL REGULATION



Jorgenson and Wilcoxen (1990)

Very black-box with thousands of parameters:

- IGEM model, which forms the basis for this paper, features over 2000 equations that jointly fit together to define an equilibrium in each period.
- Used extensively by the US Environmental Protection Agency and other organizations

Documentation: `http://www.igem.insightworks.com/docs/190.html`

- Two volumes!

Computable General Equilibrium Models

CGE and descendent DSGE: Recent Energy/Environment Applications

- Golosov, M., Hassler, J., Krusell, P., & Tsyvinski, A. (2014). "Optimal taxes on fossil fuel in general equilibrium." *Econometrica*, 82(1), 41-88.
- Barrage (2016) "Optimal Dynamic Carbon Taxes in a Climate-Economy Model with Distortionary Fiscal Policy" (IAM + CGE)
  - And citations within

"Ground-up" IO Models of a single sector

"New Empirical Industrial Organization" (Bresnahan 1989)

- Motivated by idea that individual industries are sufficiently distinct (and details sufficiently important), that cross-industry variation isn't so useful
- Focus on a single industry/market, with careful attention for institutional details, measurement of key variables, and econometric identification issues.
- Hope to learn generalizable insights from narrow focus

Some Drawbacks:

- Not clear how results generalize to other industries/markets
- Partial equilibrium
- Models often rely on equilibrium assumptions / non-transparent empirics
    - Can obscure link between estimates and underlying data/variation

Balanced overview of field/methods: Einav, L., & Levin, J. (2010). "Empirical industrial organization: A progress report." *The Journal of Economic Perspectives*, 24(2), 145-162.

A Hypothetical Example w/ Segue to Real Example

Environmental policy: A government imposes new restrictions on the emissions of pollutants from factories in an industry.

- New policy encourages adoption of a new cleaner technology
- Changes cost structure, which will affect competition
- E.g. if the new technology reduces variable costs but increases fixed costs, then expect a decline in the number of firms and an increase in the average size (output) of a firm in the industry
- Data on prices, quantities, and number of firms in the industry, together with a model of oligopoly competition, we can evaluate the effects of this policy change in the industry on both firms and consumers

Ingredients of a structural economic model in IO

1. Question
2. Economic model
   - Key features of the industry that are important to answer our empirical question
   - Should not be needlessly complicated
3. Data
4. Econometric specification of model
   - Economic models are deterministic and will never match data, so need to add heterogeneity and/or shocks
5. Estimation
6. Reporting of results

Model ingredients I

1. Description of the economic environment
   1. the extent of the market and its institutions;
   2. the economic actors; and
   3. the information available to each actor.
2. List of primitives
   1. technologies (e.g., production sets);
   2. preferences (e.g., utility functions); and
   3. endowments (e.g., assets).
3. Variables exogenous to agents and the economic environment
   1. constraints on agents' behavior; and
   2. variables outside the model that alter the behavior of economic agents
4. Decision variables, time horizons and objective functions of agents, such as:
   1. utility maximization by consumers and quantity demanded; and
   2. profit maximization by firms and quantity supplied.
5. An equilibrium solution concept, such as:
   1. Walrasian equilibrium with price-taking behavior by consumers; and
   2. Nash equilibrium with strategic quantity or price selection by firms.

Econometric specification I

Economic models are deterministic and will never match data, so need to add heterogeneity and/or shocks

- Unobserved heterogeneity
  - E.g. firms vary in their productivity
  - Must clearly specify to whom what is observed/unobserved — e.g. all firms' productivities are unobserved by the econometrician, and firms observe their own productivity but not others
- Optimization errors
  - Agents fail to exactly maximize their payoffs
- Measurement errors

Econometric specification II

Functional forms and distributional assumptions

- Economic models involve utility, profit, etc. functions of unknown form.
- For estimation we often restrict functions and distributions to be of a known parametric form.
  - Reasons: (i) computational tractability, (ii) limited data size, (iii) identification
  - E.g. utility CRRA, Cobb-Douglas production,productivity log-normal, etc

Identification: given the distribution of the observed data, is there a unique value of model parameters that match that distribution?

Ryan (2012): "The Costs of Environmental Regulation in a Concentrated Industry"

- Most previous studies that measure the welfare effects of environmental regulation (ER) have ignored dynamic effects of these policies.
- ER has potentially important effects on firm's entry and investment decisions, and, in turn, these can have important welfare effects.
- This paper estimates a dynamic game of entry/exit and investment in the US Portland cement industry.
- The estimated model is used to evaluate the welfare effects of the 1990 Amendments to the Clean Air Act (CAA).

US Portland Cement Industry

For the purpose of this paper, the most important features of the US cement industry are:

1. Indivisibilities in capacity investment, and economies of scale
2. Highly polluting and energy intensive industry
3. Local competition, and highly concentrated local markets

US Portland Cement Industry

- Portland cement is the binding material in concrete, which is a primary construction material.
- It is produced by first pulverizing limestone and then heating it at very high temperatures in a rotating kiln furnace.
- These kilns are the main piece of equipment. Plants can have one or more kilns (indivisibilities).
  - Kilns are one of the largest pieces of industrial equipment in the world
- Marginal cost increases rapidly when a kiln is close to full capacity.

US Portland Cement Industry

- Highly polluting and energy intensive industry
- The industry generates a large amount of pollutants by-products.
- Second largest industrial emitter of SO_2 and CO_2, and a major source of NOx and particulates.
  - Coal used to power/heat kiln
- High energy requirements and pollution make the cement industry an important target of environmental policies.

US Portland Cement Industry

Market Power: Transport costs + large fixed entry costs

- Local competition, and highly concentrated local markets
- Cement is a commodity difficult to store and transport, as it gradually absorbs water out of the air rendering it useless.
- Transportation costs per unit value are large.
- This is the main reason why the industry is spatially segregated into regional markets. These regional markets are very concentrated.

The Regulation / Policy Change

The Clean Air Act (CAA) is the largest environmental policy in the United States

- The 1990 CAA Amendments were a major revision.
  - Probably most important new environmental regulation affecting this industry in the last three decades.
- It added new categories of regulated emissions + increased stringency of existing regs
- Cement plants were required to undergo an environmental certification process. Environmental permits for operation.
- This regulation may have increased sunk costs, fixed operating costs, and/or investment costs in this industry.

Evaluation of Policy Effects

- Previous evaluations of these policies have ignored effects on entry/exit and on firm's capacity investment.
  - Or have explored entry/exit in ad hoc way (e.g. Henderson 1996, Becker and Henderson 2000, List et al. (2003))
- Very little work exploring how regulation contributes to marginal costs and/or prices. Hard to say much about welfare without
- Moreover, ignoring effects on entry/exit (concentration) could lead researchers astray: $P \times \underline{Q}$

Empirical Strategy

Model the cement industry: oligopolists make optimal decisions over entry, exit, production, and investment given the strategies of competitors.

- Estimate model using a 20 year panel and allowing the structural parameters to differ before and after the 1990 regulation.
- Changes in cost parameters are attributed to the new regulation.

Preview of Empirical Results

- Amendments roughly doubled sunk costs of entry, to $35M. Larger entry cost reduced net entry and # of plants, increasing market power.
- Amendments led to higher investment by incumbents, but lower aggregate market capacity.
- Consumer welfare decreased 25% due to lower entry and increased market power (approx. $1.2B).

Data

USGS Minerals Yearbook

- Market-level data for prices and quantities
- 27 markets covering United States 1980-1999 - 517 market-year observations
- Energy prices, labor inputs from Dept. Energy

Portland Cement Association Plant Information Survey

- Every plant in United States 1980-1998
- Kiln-level data on capacity and production
- 2233 plant-year observations

Estimation

Estimate a dynamic game in the spirit of Bajari, Benkard, and Levin (2007)

A "two-step" approach:

1. Stage 1:
   - Estimate short run profit function and market demand
   - Estimate policy functions for exit, entry, and investment (as function of state vector, i.e., plant capacities in market)
2. Stage 2: Find parameters that rationalize policies as best responses
   - Estimate transition process for state variables $\Pr(s'|s)$ and compute value functions
   - Estimate dynamic parameters (capacity adjustment cost, distribution of entry costs and scrap values) by using equilibrium conditions for entry, exit, investment

Timing of information and decisions

1. All firms observe the public state vector S_t
2. Investment, entry and exit decisions
    1. Incumbents observe a private scrap value and choose to stay/exit.
    2. Potential entrants observe private entry cost draw and an investment cost draw
    3. Incumbents that decided to stay in observe investment and divestment cost draws

   All firms make entry and investment decisions simultaneously and pay adjustment costs
3. Incumbent firms compete over quantities (simultaneous move) in the product markets
4. Short run profits are realized
5. Entry and exit decisions are realized
6. State vector is updated as new capacities come on-line

Empirical Model: Stage 1.a.

- Constant Elasticity Market Demand – estimate with market level data:

$$\ln Q_{mt} = \alpha_0 + \alpha_1 \log P_{mt} + \alpha_{2m} + \alpha_{3t} X_{mt} + \epsilon_{mt}$$

  - α_1 is the elasticity of demand
  - X is a vector of covariates that influence demand (log-population, log-construction permits).
  - α_{2m} is a set of market fixed effects.
- Instrument for prices: coal prices, gas prices, electricity rates and wage rates.

Empirical Model: Stage 1.a.

TABLE III

CEMENT DEMAND ESTIMATES[a]

	I	II	III	IV	V	VI
Price	−3.21	−1.99	−2.96	−0.294	−2.26	−0.146
	(0.361)	(0.285)	(0.378)	(0.176)	(0.393)	(0.127)
Intercept	21.3	10.30	20.38	−3.41	11.6	−6.43
	(1.52)	(1.51)	(1.56)	(1.09)	(2.04)	(0.741)
Log population		0.368		0.840	0.213	0.789
		(0.0347)		(0.036)	(0.074)	(0.033)
Log permits					0.218	0.332
					(0.072)	(0.035)
Market fixed effects	No	No	Yes	Yes	No	Yes

[a]Dependent variable is logged quantity. Instruments were gas prices, coal prices, electricity prices, and skilled labor wage rates. There are a total of 517 observations.

Profits from selling concrete

Cost function for firm i in market:

$$C_i(q_i;\delta) = \delta_0 + \delta_1 q_i + \delta_2 I(q_i > \nu_{si}) \times ((q_i - \nu_{si})^2)$$

Operating above efficient scale is costly
Short run profits:

$$\pi_i = q_i(P - \delta_1) - \delta_0 - \delta_2 I(q_i > \nu_{si}) \times ((q_i - \nu_{si})^2)$$

- δ_1, δ_0 is constant marginal,fixed cost
- δ_2 is common cost when nearing capacity
- ν is common threshold where increasing MC kicks in

Empirical Model: Stage 1.b

- Use FOC for output choice (MR = MC) and solve for q_{it}^*
- Choose the parameters of the cost function $(\delta_1, \delta_2, \nu)$ in each of the two regulatory regimes to minimize deviation between q_{it}^* and q_{it}. See Table 4.

Empirical Model: Stage 1.b

TABLE IV

PRODUCTION FUNCTION RESULTS[a]

Production Function Estimates		
Parameter	Coefficient	Standard Error
Marginal cost (δ_1)	31.58	1.91
Capacity cost (δ_2)	1.239	0.455
Capacity cost threshold ($\widetilde{\nu}$)	1.916	0.010
Marginal cost post-1990 shifter	2.41	3.33
Capacity cost post-1990 shifter	−0.0299	0.22
Capacity cost threshold post-1990 shifter	0.0917	0.0801

Prices, Revenues, and Profits		
Variable	Value	Standard Deviation
Price	57.81	16.83
Revenues	39,040	19,523
Costs	22,525	11,051
Profit	16,515	12,244
Margin	39.29 percent	18.21 percent

[a]The binding threshold at which the capacity costs become important is restricted to $[0, 1]$ by estimating a logit probability: $\nu = \exp(\widetilde{\nu})/(1.0 + \exp(\widetilde{\nu}))$. At the estimated value of 1.916, this implies that capacity costs start to bind at an approximately 87 percent utilization rate.

Empirical Model: Stage 1.c

- Policy functions depend on state vector of capacities.
  - They describe actual (optimal) action for each state.
- Exit: Probit model of plant exit.
  - Explanatory variables: capacity, rival capacity, regime dummy
- Entry: Probit model of plant entry.
  - Explanatory variables: total rival capacity, regime dummy.

Empirical Model: Stage 1.c

TABLE VIII

ENTRY AND EXIT POLICY RESULTS[a]

Specification	I	II	III	IV
Exit Policy				
Own capacity	−0.0015661	−0.0015795		
	(0.000268)	(0.0002712)		
Competitors' capacity	0.0000456	0.0000379		
	(0.0000173)	(0.0000249)		
Population		0.0590591		
		(0.1371835)		
After 1990	−0.5952687	−0.606719	−0.6328867	−0.4623664
	(0.1616594)	(0.1639955)	(0.157673)	(0.1910193)
Own capacity per capita			−0.0005645	−0.0010199
			(0.0001255)	(0.0002164)
Competitors' capacity per capita			0.0000744	0.0002379
			(0.00000286)	(0.0001023)
Constant	−1.000619	−1.019208	−1.664808	−1.529715
	(0.1712286)	(0.176476)	(0.1475588)	(0.3526938)
Region fixed effects	No	No	No	Yes
Log-likelihood	−227.21	−227.12	−238.54	−217.38
Entry Policy				
Competitors' capacity	0.0000448	−0.0003727		
	(0.0000365)	(0.0002351)		
After 1990	−0.6089773	−0.8781589	−0.602279	−1.003239
	(0.2639545)	(0.3229502)	(0.2651052)	(0.337589)
Constant	−1.714599	−0.454613	−1.665322	−0.3434765
	(0.2152315)	(0.7086509)	(0.2642566)	(0.6624767)
Competitors' capacity per capita			0.000026	−0.0003633
			(0.000038)	(0.0001766)
Region fixed effects	No	Yes	No	Yes
Log-likelihood	−70.01	−56.47	−70.491	−55.53
Prob > χ^2	0.0177	0.4516	0.0287	0.3328

Less entry and exit after 1990

Stage 1 Estimates Allow Forward Simulation

Policy function estimates are used simulate state vector forward in time $S_1, S_2, ..., S_T$ from a given starting point S_0. For example,

1. For inactive firms ($s_{it} = 0$), entry decision using $Pr(entry|S_t)$. Update the state vector for next period
2. For an active firm ($s_{it} > 0$), draw exit probability with $Pr(exit|S_t)$. Update the state vector
3. Future states are ones that are consistent with optimal decisions by firms
4. Can be repeated many times to generate many paths for state variables

Stage 2

Estimate dynamic parameters adjustment cost parameters for investment γ and distribution of entry costs/scrap value

Insights from Bajari, Benkard, Levin (2007):

- "True" policy functions yield higher NPV of payoffs than perturbed policy functions

Objective for estimation is to choose dynamic parameters to minimize the possibility of observing higher NPV from perturbed policy functions

Stage 2: Recover "Dynamic" Parameters

TABLE IX

DYNAMIC PARAMETERS[a]

	Before 1990		After 1990		Difference	
	Mean	SE	Mean	SE	Mean	SE
Parameter						
Investment cost	230	85	238	51	−8	19
Investment cost squared	0	0	0	0	0	0
Divestment cost	−123	34	−282	56	−155	35
Divestment cost squared	3932	1166	5282	1130	1294	591
Investment Fixed Costs						
Mean (μ_γ^+)	621	345	1253	722	653	477
Standard deviation (σ_γ^+)	113	72	234	145	120	97
Divestment Fixed Costs						
Mean (μ_γ^-)	297,609	84,155	307,385	62,351	12,665	34,694
Standard deviation (σ_γ^-)	144,303	41,360	142,547	29,036	109	17,494
Scrap Values						
Mean (μ_ϕ)	−62,554	33,773	−53,344	28,093	9833	21,788
Standard deviation (σ_ϕ)	75,603	26,773	69,778	27,186	−6054	11,702
Entry Costs						
Mean (μ_κ)	182,585	36,888	223,326	45,910	43,654	21,243
Standard deviation (σ_κ)	101,867	22,845	97,395	14,102	−6401	12,916

Increase in entry costs post 1990 will greatly reduces the chances that marginal firms enter a market

Counterfactuals: Policy Experiment

- **Counterfactual**: use pre-1990 distribution of sunk entry cost to simulate the Markov Perfect Nash Equilibrium for the data after 1990.
- The difference in outcomes are attributed to the Amendments Compute welfare measures (profits and consumers' surplus)
- Two scenarios:
  1. An initial state vector of four potential entrants and no incumbents
  2. Two incumbents, with joint capacities of 2.25M tons of cement per year, and two potential entrants.

Counterfactuals

TABLE X

COUNTERFACTUAL POLICY EXPERIMENTS[a]

	Low Entry Costs (Pre-1990)		High Entry Costs (Post-1990)		Difference	
	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
De Novo Market						
Total producer profit ($ in NPV[b])	43,936.11	(7796.98)	33,356.87	(7767.22)	−11,182.04	(7885.20)
Profit firm 1 ($ in NPV)	45,126.30	(10,304.87)	34,321.61	(9520.93)	−11,965.22	(11,684.96)
Total net consumer surplus ($ in NPV)	1,928,985.09	(62,750.34)	1,848,872.52	(75,729.17)	−66,337.44	(58,404.32)
Total welfare ($ in NPV)	2,116,810.12	(74,265.74)	1,992,937.65	(96,634.83)	−119,771.39	(49,423.06)
Periods with no firms (periods)	1.29	(0.08)	1.32	(0.09)	0.04	(0.08)
Periods with one firm (periods)	1.51	(0.37)	2.60	(0.86)	1.05	(0.78)
Periods with two firms (periods)	8.17	(4.68)	21.43	(9.92)	12.26	(9.99)
Periods with three firms (periods)	54.71	(20.22)	91.35	(21.27)	33.38	(18.85)
Periods with four firms (periods)	135.91	(24.64)	84.03	(32.67)	−46.73	(25.04)
Average size of active firm (tons)	980.71	(76.18)	1054.65	(85.17)	73.42	(74.01)
Average market capacity (tons)	3467.85	(188.21)	3352.23	(208.94)	−112.75	(107.84)
Average market quantity (tons)	3094.23	(161.57)	2987.61	(177.58)	−105.69	(89.41)
Average market price	66.66	(1.90)	68.12	(2.11)	1.47	(1.14)

(*Continues*)

Counterfactuals

TABLE X—*Continued*

	Low Entry Costs (Pre-1990)		High Entry Costs (Post-1990)		Difference	
	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
Mature Market						
Total producer profit ($ in NPV)	223,292.75	(4831.95)	231,568.23	(5830.42)	9551.01	(5465.77)
Profit firm 1 ($ in NPV)	549,179.30	(14,138.37)	579,742.32	(20,446.75)	32,968.00	(19,161.33)
Total net consumer surplus ($ in NPV)	2,281,584.08	(52,663.88)	2,208,573.20	(62,906.14)	−62,974.37	(32,662.05)
Total welfare ($ in NPV)	3,178,504.60	(60,267.34)	3,141,916.43	(62,618.02)	−30,099.56	(18,078.21)
Periods with no firms (periods)	0.00	(0.00)	0.00	(0.00)	0.00	(0.00)
Periods with one firm (periods)	0.00	(0.00)	0.00	(0.00)	0.00	(0.00)
Periods with two firms (periods)	8.63	(3.57)	23.20	(10.05)	14.13	(10.00)
Periods with three firms (periods)	61.32	(16.83)	98.37	(21.49)	35.73	(20.16)
Periods with four firms (periods)	131.52	(20.10)	78.38	(31.99)	−50.00	(27.39)
Average size of active firm (tons)	989.33	(44.45)	1059.31	(63.41)	73.48	(54.64)
Average market capacity (tons)	3502.49	(171.20)	3371.03	(191.87)	−117.56	(73.19)
Average market quantity (tons)	3123.42	(150.66)	3001.98	(165.51)	−108.16	(69.48)
Average market price	66.82	(1.64)	68.36	(1.91)	1.44	(0.85)

[a] Industry distributions were simulated along 25,000 paths of length 200 each. All values are present values denominated in thousands of dollars. The new market initially has no firms and four potential entrants. The incumbent market starts with one 750,000 TPY incumbent and one 1.5M TPY incumbent and two potential entrants. Counts of active firms may not sum to 200 due to rounding off. Means and standard deviations were calculated by subsampling.

[b] Where NPV denotes Net Present Value.

Implications

- Static analysis of the engineering costs ignore the dynamic costs to consumers
- Extrapolating costs to the US, leads to a lower bound estimate of \$810M (\$486M) and upper bound of \$3.2B (\$1.3B)
- Negative consequences of environmental regulation through restricted competition in the product market are partially offset by emissions reductions

Epilogue: Written in 2004 - published in 2012

How to Estimate/Measure Social Cost of Regulation?

Three Main Approaches

1. (Computable) General Equilibrium Models + Counterfactuals
2. **"Ground-up" IO Models of a single sector + Counterfactuals**
   Other representative papers:
   - Fowlie (2010), Lim and Yurukoglu (2018), Abito (2017), Ito and Reguant (2016), Reguant (2014), Fowlie, Reguant, and Ryan (2016), Timmins (2002), Jha (2014)
3. Program Evaluation Methods (i.e. ex post analysis)

How Well Do Different Methods Capture Entirety of Compliance Costs?

Other "NEIO" Papers with Energy/Environment Applications

Meredith's job market paper, Fowlie (2010)

Research Question: Does heterogeneity in electricity market regulation affect how coal plants choose to comply with NOx emissions trading program?

- Preexisting distortions in product markets that are subject to CAT regulation may interfere with the emissions permit market's ability to operate efficiently.
- Recent wave of electricity industry restructuring in the United States has resulted in significant interstate variation in economic regulation.

Quick Segue: Natural Monopoly Regulation

Goal of policy to handle natural monopolies: single firm producing efficiently and pricing at the socially optimal level

- First objective can be achieved by issuing monopoly to private firm
- Profit maximization leads to price above marginal cost $\Rightarrow$ DWL

"Economic regulation" forces firms to price in socially efficient manner:

- Regulatory agency that sets price and gives firm normal rate of return
- Problems: poor incentives and other distortions (Averch-Johnson)

Empirical Question:
Do regulated monopolies perform "better" than unregulated monopolies?

Effects of Economic Regulation:

Comparing regulated and unregulated firms or markets.

Stigler and Friedland (1962)

- One of the first empirical analyses exploring effects of utility regulation
- Estimate hedonic price equation: price of electricity for states from 1907 to 1930s
- Coefficient of interest: dummy variable indicating whether electricity prices were regulated by state commission or not

Findings

- Concluded that regulation did little to reduce prices below unregulated monopoly levels.
- Regulation doesn't work so "why bother"

Effects of Economic Regulation:

Comparing regulated and unregulated firms or markets.

Stigler and Friedland (1962): Criticisms

- Coding mistake (dummy $= 10$, not 1)
  - actually a 20% *decrease* in prices

- Endogeneity of state commission regulation

Enduring Legacy: At the time a shocking result that stimulated research along various fronts (incentive regulation, regulatory capture, etc...)

Rate of Return Regulation ⇒ Incentive Regulation

Basic shortcomings of regulatory regime have prompted interest in incentive regulation

1. Asymmetric Information: Regulators not good at distinguishing efficient from inefficient behavior
2. Lack of incentives: managerial or x-inefficiencies if all costs passed to consumers/rates... though regulatory lag (e.g. rate cases) may provide informal incentives for cost minimization

Genesis of "Incentive Regulation": How can we do better?

Regulation Seems Complicated and Fraught With Issues

Why not let market forces promote efficiency

- Large movement to deregulate many sectors in 80's and 90's
- Restructuring, requiring firms to divest along vertical segment lines, has become common.

Deregulation and Restructuring in Practice

- Segments viewed as competitive (e.g. electricity generation), have been increasingly deregulated.
- Network segments that continue to operate under natural monopoly cost conditions (e.g. electricity transmission grids), generally required to provide access to competitive suppliers, often at terms subject to continued regulatory oversight.

"Competition where possible, regulation when necessary"

- Where economic regulation retained, it has become more market-oriented

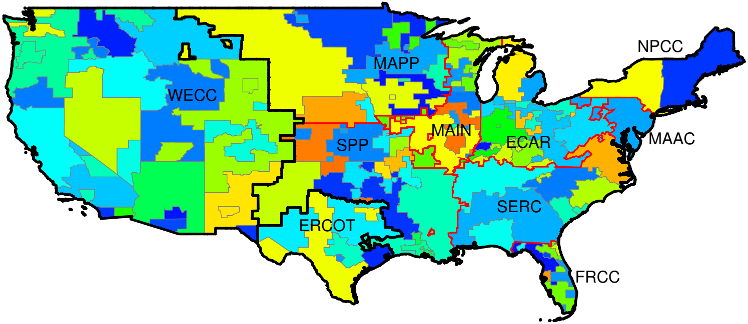
A Brief History of the Electricity Sector

- Was long believed to be a natural monopoly.
- Grew up as a balkanized patchwork of regulated, vertically integrated utilities
- Rates were set by State Public Utility Commissions.
- "Prudent" cost recovery ensured regulation of investments and operations.
- Units dispatched based on engineering estimates of cost within $\approx$ 100 Power Control Areas.

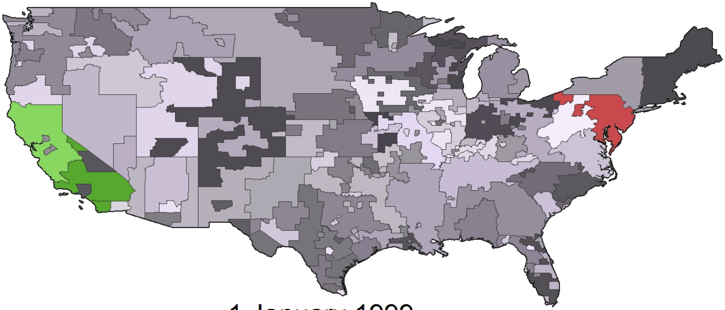
A Brief History of the Electricity Sector

- Federal Energy Regulatory Commission (FERC) begins encouraging competitive generation as part of broader deregulatory push in late 1970's.
- Late 1990s: Independent System Operators (ISO) / Regional Transmission Organizations (RTO) begin taking over dispatch in select areas areas.
- ISO/RTOs consolidate Power Control Areas in to a single dispatch algorithm
- Generating units are scheduled according to bids in day-ahead, uniform price auctions instead of engineering estimates.
- Real-time auctions determine who actually produces electricity.

Balancing Authorities in 1999



Balancing Authorities Becoming Markets



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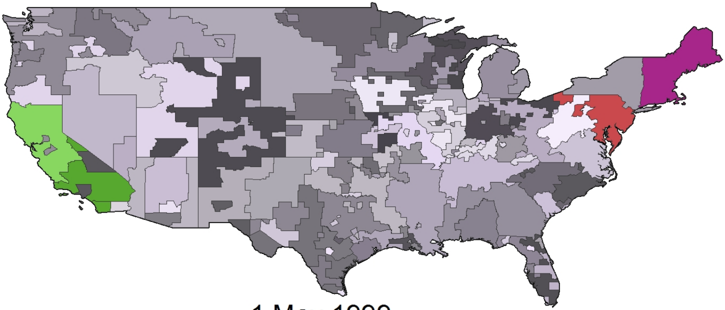
Balancing Authorities Becoming Markets



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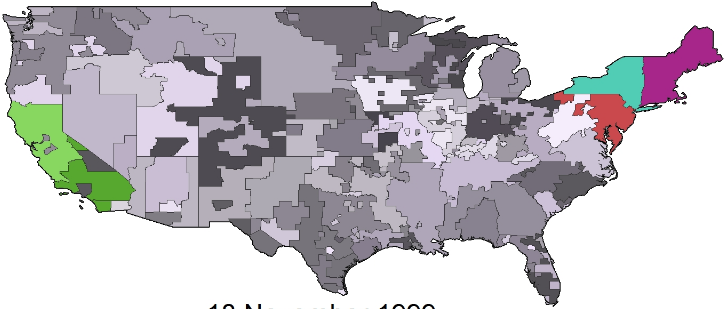
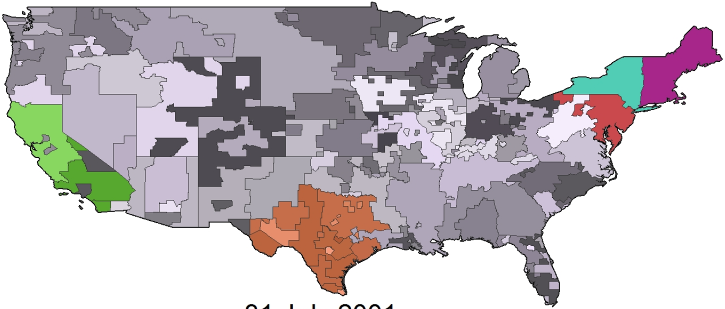
Balancing Authorities Becoming Markets



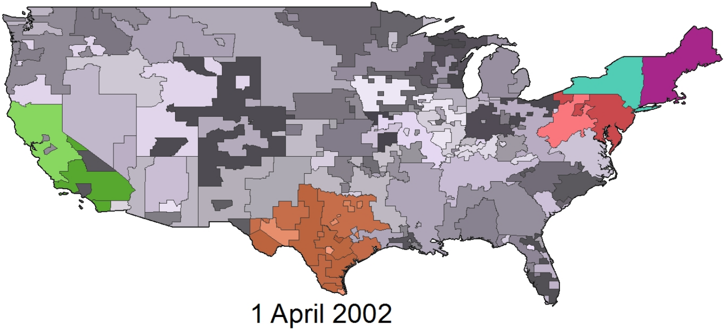
18 November 1999

Balancing Authorities Becoming Markets

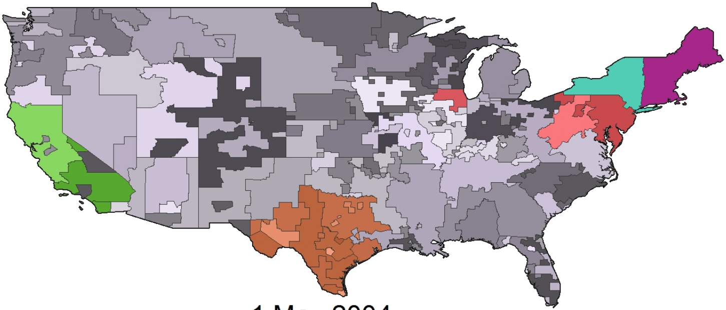


31 July 2001

Balancing Authorities Becoming Markets



Balancing Authorities Becoming Markets



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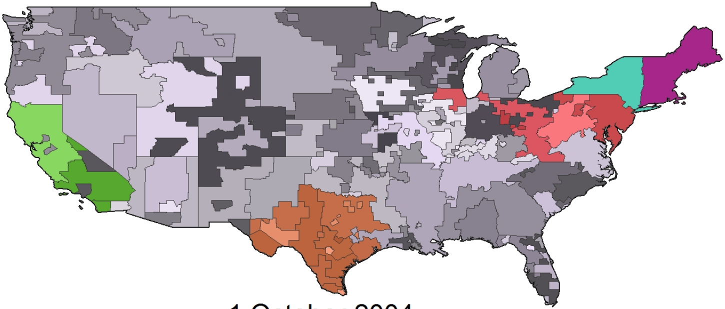
Balancing Authorities Becoming Markets



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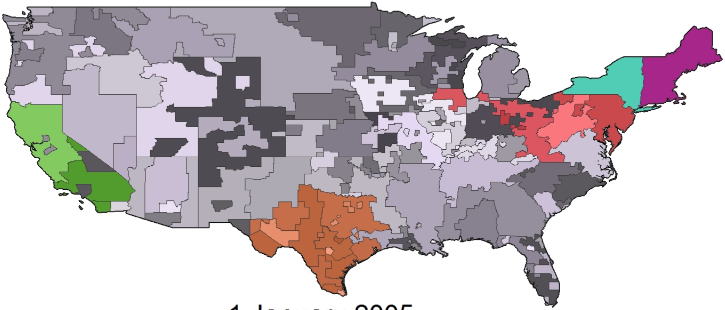

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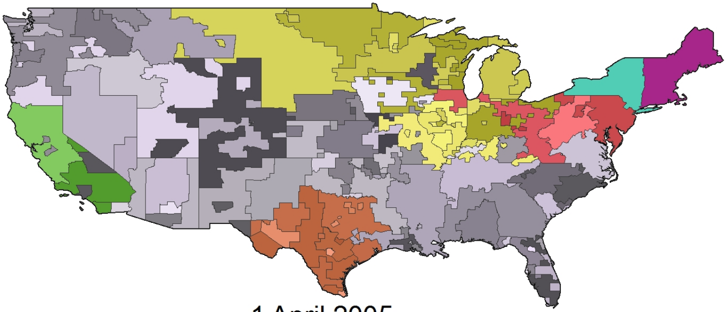
Balancing Authorities Becoming Markets



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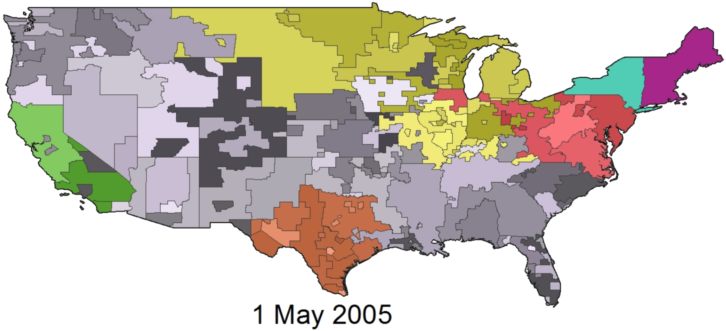

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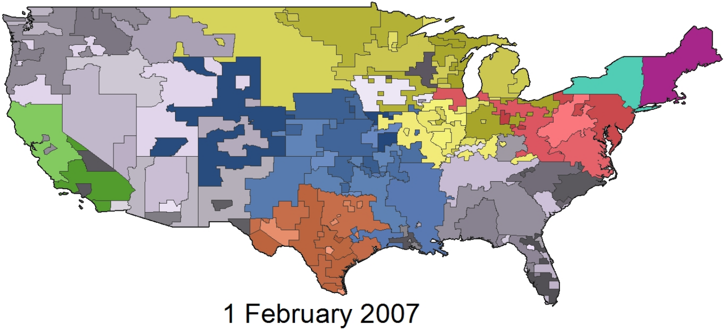

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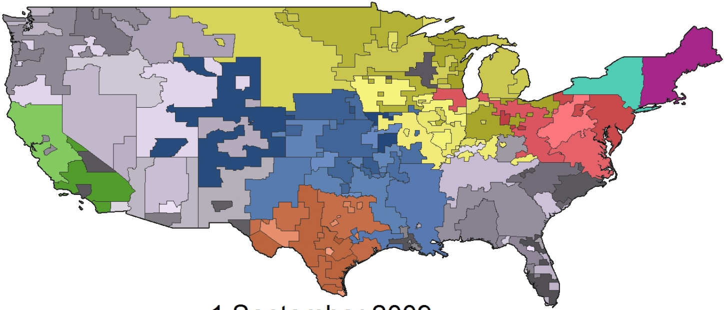

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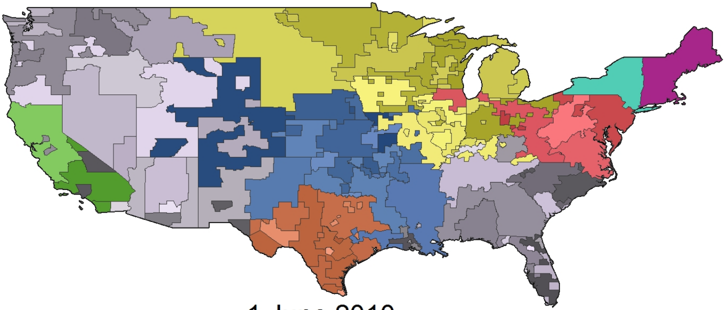
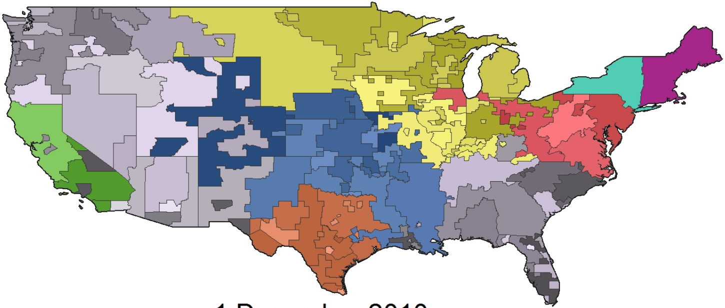
Balancing Authorities Becoming Markets



1 June 2010

Balancing Authorities Becoming Markets



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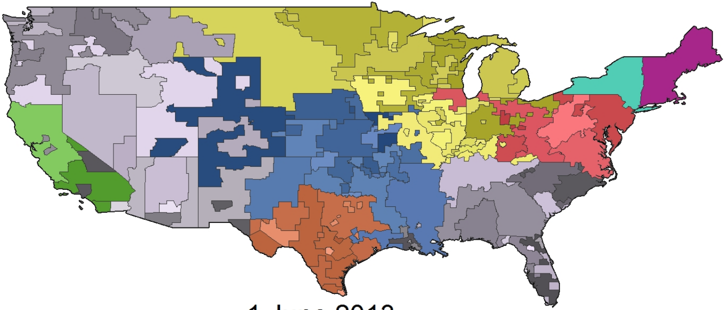

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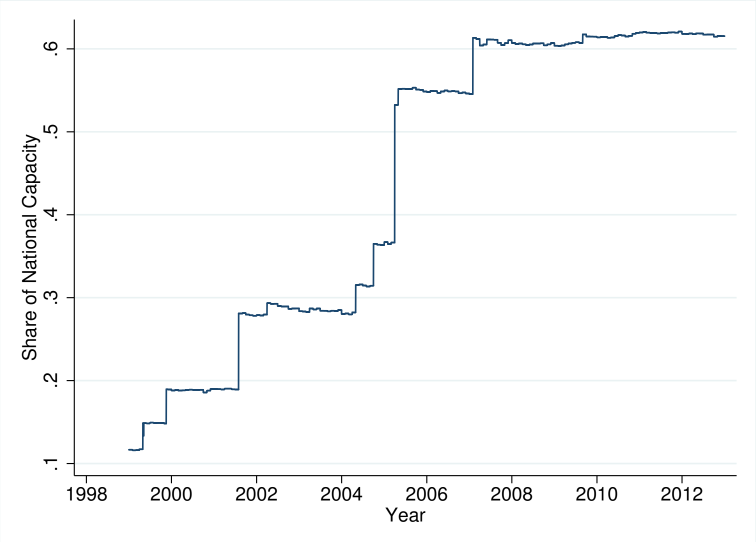
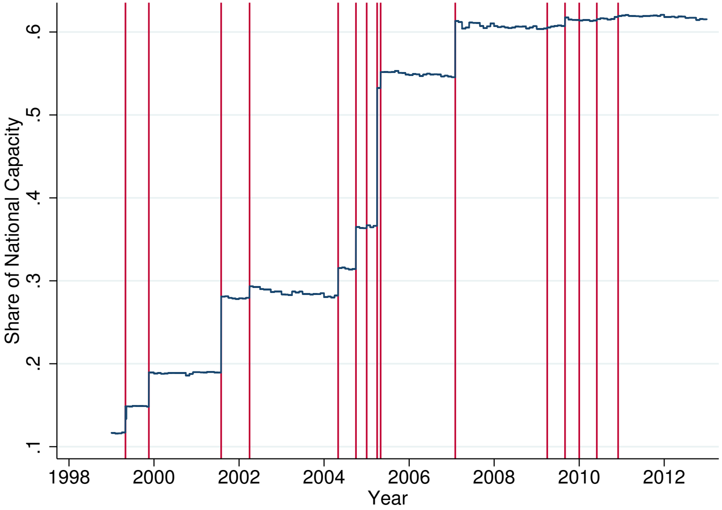
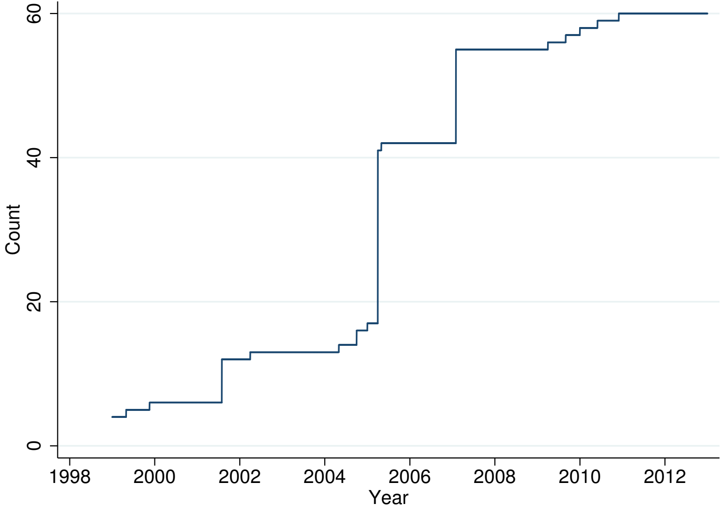
Percent of Generation Capacity Dispatched by Markets



Percent of Generation Capacity Dispatched by Markets



Number of 1999 Power Control Areas Under Market Dispatch



Other "NEIO" Papers with Energy/Environment Applications

Meredith's job market paper, Fowlie (2010)

Research Question: Does heterogeneity in electricity market regulation affect how coal plants choose to comply with NOx emissions trading program?

- Preexisting distortions in product markets that are subject to CAT regulation may interfere with the emissions permit market's ability to operate efficiently.
- Recent wave of electricity industry restructuring in the United States has resulted in significant interstate variation in economic regulation.

Why is the existing literature crappy, nonexistent, and/or unresolved?

Empirical Setting: NOx Budget Program + Electricity Market Deregulation

- Emissions trading program that limits emissions of NOx from large stationary sources in 19 eastern states
- Do compliance (i.e. abatement) technology choices differ between firms in regulated/deregulated markets?

Fowlie (2010)

Model demand for utility to adopt different compliance options

- Abatement choice as functions of a plant type (e.g. regulated), plant's cost of capital, cost recovery parameters, and scale parameter of EV distribution
- Using random coefficients logit

NEIO Demand Systems

A lot of "structural estimation" is figuring out how to correctly estimate/model demand

- Static, dynamic, heterogeneity, etc...

Static Models All Have a Similar Flavor (e.g. BLP)

1. Estimate demand using discrete choice (mixed logit / random coefficients)
2. Assume market structure which implies a pricing rule
   - Pricing rule delivers relationship between demand elasticity and markups
3. Combine imputed markup with information on prices to get marginal cost: (P=MC$\times$Markup)
   - With costs data can construct supply curve... and combine with demand estimates + counterfactuals
   - "Estimating costs without cost data"

Fowlie (2010)

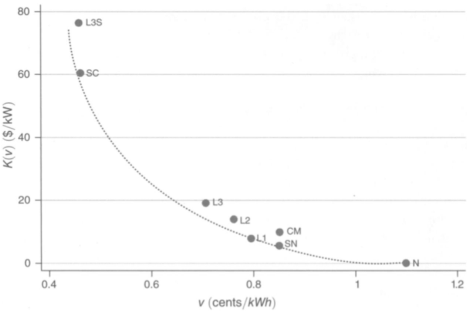


FIGURE 1. ESTIMATED NO_x CONTROL COSTS FOR A 512 MW T-FIRED BOILER

Strategy code	Technology	lbs NO_x/mmBtu
N	No retrofit	0.42
SN	Selective Non-Catalytic Reduction (SNCR)	0.34
CM	Combustion modification	0.33
L1	Low NO_x burners with overfire air option 1	0.31
L2	Low NO_x burners with overfire air option 2	0.28
L3	Low NO_x burners with overfire air options 1&2	0.26
SC	Selective Catalytic Reduction (SCR)	0.13
L3S	L3 + SCR	0.11

Fowlie (2010)

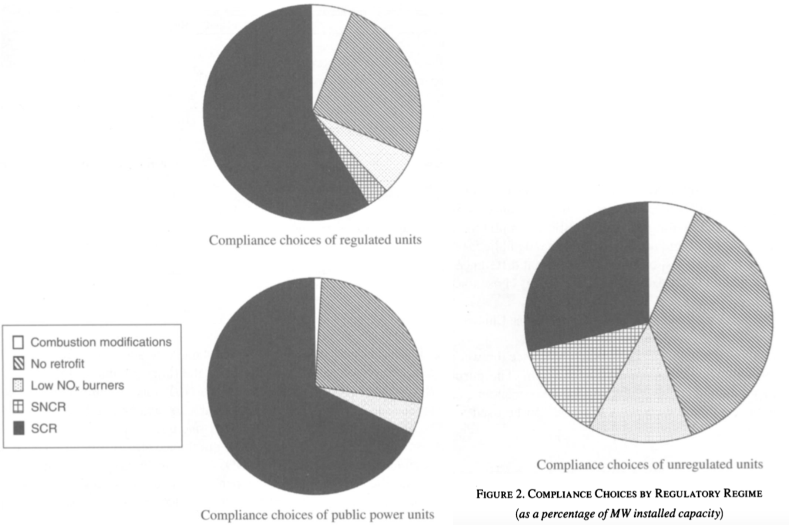


FIGURE 2. COMPLIANCE CHOICES BY REGULATORY REGIME

(as a percentage of MW installed capacity)

Fowlie (2010)

Two Counterfactuals:

1. One in which all coal plants in the emissions trading program are subject to electricity rate regulation
2. One in which all facilities operate as deregulated entities supplying restructured electricity markets.

Findings:

1. Deregulated plants in restructured electricity markets were less likely to adopt more capital intensive environmental compliance options as compared to regulated or publicly owned plants.
2. Larger share of the permitted pollution is emitted in states where air quality problems more severe (i.e. due to heterogeneity in electricity market regulations)

How to Estimate/Measure Social Cost of Regulation?

Three Main Approaches

1. (Computable) General Equilibrium Models + Counterfactuals
2. "Ground-up" IO Models of a single sector + Counterfactuals
3. **Program Evaluation Methods (i.e. ex post analysis)**

How Well Do Different Methods Capture Entirety of Compliance Costs?

Growing Lit Exploring Effects of Deregulation in Electricity Markets

Regulated Markets Associated with Inefficiencies in...

- Coal procurement (Cicala, 2015, Jha, 2017)
- Labor and non-fuel expenses (Fabrizio, Rose and Wolfram, 2007)
- Environmental compliance methods (Fowlie, 2010)
- Nuclear power plant operating efficiency (Davis and Wolfram, 2012)

Performance in Deregulated Natural Monopoly Sectors

Electricity Deregulation: Not all rosy...

- Deregulation associated with generator market power:
- Generators bidding above MC; strategically withholding capacity from market to increase prices (Wolfram 1999, Borenstein et al. 2000, Joskow and Kahn 2001)

Other "costs" of deregulation:

- 'Command and control' by vertically integrated firm may reduce coordination costs in electricity markets
- Reserve margins and hence system operating costs have increased as a result of moving to a dispatch market.
  - def: a reserve margin of 15% means that an electric system has excess capacity in the amount of 15% of expected peak demand

Incentive Regulation: Empirical Evidence

Fabrizio, Rose, and Wolfram (2004)

- Mid-1990s several states restructured their utility markets - wholesale markets for generation + nonutility generators
- Examine performance of IOU vs. municipal utility before/after restructuring
- Plants most affected by restructuring reduced labor and nonfuel expenses by 3-5% relative to other investor-owned utility plants, and by 6-12% relative to government owned plants that were largely insulated from restructuring incentives.

Why is the existing literature crappy, nonexistent, and/or unresolved?

Fabrizio, Rose, and Wolfram (2004)

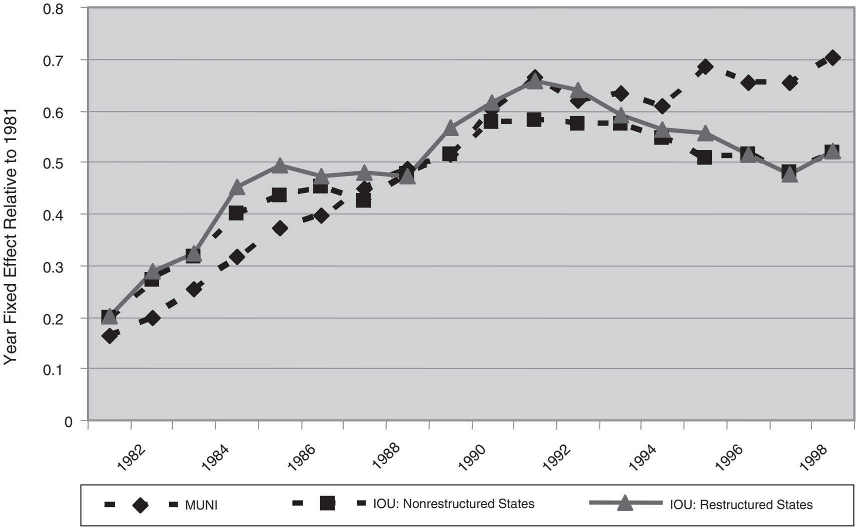


FIGURE 1. LABOR INPUT DEMAND YEAR-EFFECTS BY REGULATORY STATUS (BASIC GLS-IV SPECIFICATION)

Fabrizio, Rose, and Wolfram (2004)

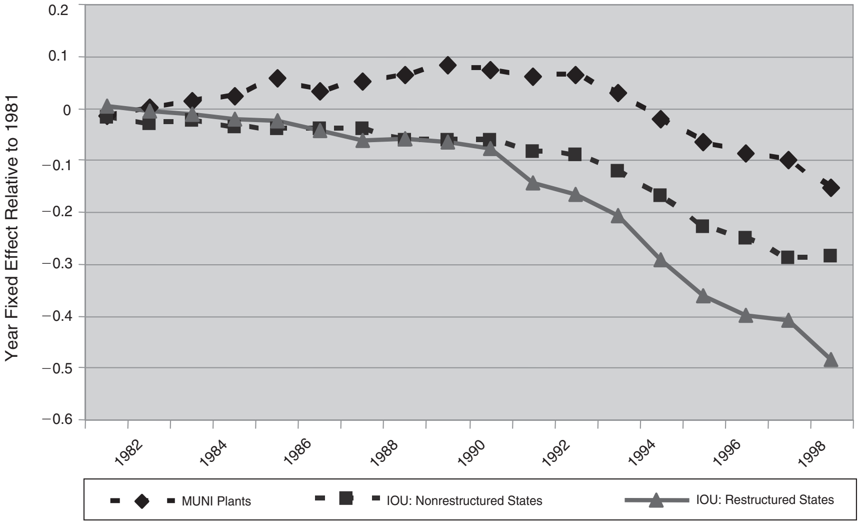


Figure 2. Nonfuel Expense Input Demand Year-Effects by Regulatory Status (Basic GLS-IV Specification)

Cicala (2015): When Does Regulation Distort Costs

What is the question, and why is it interesting?

- Shift from cost-of-service regulation (i.e. cost-plus) to market based dispatch
- What happened to input costs, specifically coal procurement? Why?

Why is the existing research crappy, nonexistent, and/or unresolved?

- FRW look at period leading up to deregulation (e.g. FRW have data to 1999). Lots of divestment occurred 2000+
- FRW do not observe input costs of plants sold to non-utility generators
- FRW do not measure fuel input costs $\approx$ 80% variable costs

What is he going to do to solve it?

- Restricted access data from EIA on coal procurement before/after deregulation
- Data post 1999
- Matching estimator

Cicala (2015): When Does Regulation Distort Costs

Fuel Procurement in U.S. Electricity Generation

- Shift from cost-of-service regulation (i.e. cost-plus) to market based dispatch
- What happened to input costs, specifically coal procurement? Why?

Research Design:

- State-year, difference-in-differences
- Combined with matching to refine treatment

Findings:

- Deregulated plants substantially reduce the price paid for coal
- Tend to employ less capital-intensive production techniques
- Deregulation also led to a shift toward more productive coal mines.

Cicala (2015): When Does Regulation Distort Costs

How does Cost-of-Service Regulation Distort Production?

1. Capital bias when rate of return that exceeds the cost of capital (Averch and Johnson (1962))
2. Impossible to induce cost-reducing effort when regulator unable to observe effort (or cost of effort) (Laffont and Tirole, 1986)
3. Regulatory capture: interest groups (such as coal producers) influence the regulator's decision on which costs to allow

Cicala (2015): When Does Regulation Distort Costs

Testing Theories of Regulatory Distortion

1. Capital Bias: Look at capital intensity of pollution abatement investments
2. Asymmetric information: Look at effects in markets with observable input prices (e.g. natural gas)
3. Regulatory capture: Look at fraction of coal purchases from in-state

Research Design: Identifying Assumption:

- Fuel purchasing opportunities are identical between "treatment" and "control" facilities after controlling for time-invariant differences.

Confounds?

- Transport costs for coal + railroad deregulation
- Time varying shocks that covary with deregulation
- SUTVA: control plants participate in common markets (e.g. for coal)

Cicala (2015): When Does Regulation Distort Costs

Solution to Identifying Challenges: “Nearest neighbor matching”

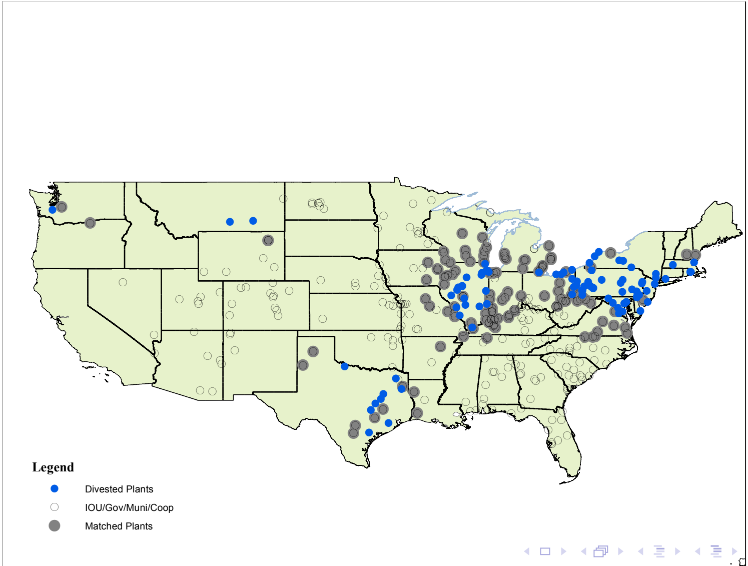
- Leverage close geographical proximity for matches (same market)
- Match on coal “rank” (quality)

Mean differences between “treatment” plants and plants that are either:

- Nearby in distance (but not in deregulated market)
- Nearby in terms of input use technology (but not in deregulated market)

Cicala (2015): When Does Regulation Distort Costs

Figure 1: Coal-Fired Plants in The United States, 1990-2009



Cicala (2015): When Does Regulation Distort Costs

Table 4: Coal: Matched DID Estimates of $Log(Price)$ and Divestiture

	(1)	(2)	(3)	(4)	(5)	(6)
Post-Divest	–0.124***	–0.188***	–0.152*	–0.124***	–0.128***	–0.136**
	(0.044)	(0.058)	(0.077)	(0.045)	(0.046)	(0.064)
m Nearest Neighbors				10	5	1
Proximity Threshold (mi.)	200	100	50			
Year-Month FE	Yes	Yes	Yes	Yes	Yes	Yes
Facility FE	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.721	0.712	0.668	0.723	0.726	0.738
Facilities	230	146	69	198	166	121
Divested Facilities	87	74	39	87	87	87
Obs.	47024	28449	12682	37495	32958	23336

Note: Dependent variable is $Log(Price)$ of Coal per MMBTU, including shipping costs. Non-Divested facilities receive weight $\frac{1}{m_{-j}}$ for each matched divested facility j burning the same rank of coal in 1997, subject to the indicated matching criterion. Standard errors clustered by facility in parentheses. * p<0.1, ** p<0.05, *** p<0.01

Cicala (2015): When Does Regulation Distort Costs

Headline findings:

1. Price of coal drops by 12% at deregulated plants (relative to control)
2. Deregulated plants disproportionately switch to burning low-sulfur coal rather than install a capital-intensive abatement equipment (i.e. to comply with environmental regulations)
3. Deregulated plants expand coal imports from out of state by 25%
4. Reallocation of coal purchases toward more productive mines
5. Operators of divested coal-fired plants spend \$1B less per year on coal due (but only account for 25% of coal-fired capacity)

Recent follow up work by Jha (2015, 2017)

- "Regulatory Induced Risk Aversion: Coal Procurement at U.S. Power Plants"
- "Dynamic Regulatory Distortions: Coal Procurement at U.S Power Plants" (Similar empirical setup to Ryan 2012)

Cicala (2022)

What is the question, and why is it interesting?

- What are the welfare gains from moving to a deregulated, wholesale electricity market?
- Do markets (including all of their flaws) outperform other methods for electricity dispatch?

Why is the existing research crappy, nonexistent, and/or unresolved?

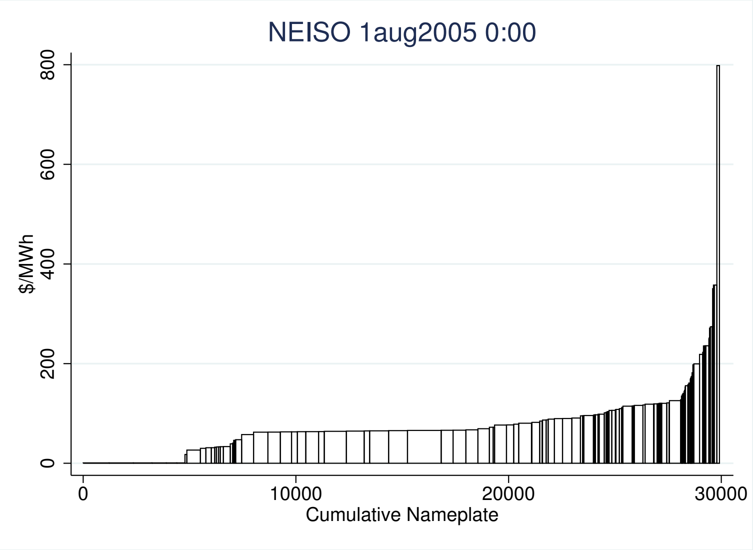
- Most related work focusing on costs of market power

  (e.g. Wolfram (1999); Wolak and Patrick (1997); Reguant (2014); Ito and Reguant (2016); Borenstein et al. (2002); Joskow and Kahn (2002); Bushnell et al. (2008); Puller (2007)); Mansur (2001, 2008)); Hortacsu and Puller (2008))
- Existing work looking at changes in input costs... limited, direct connection to economic welfare (i.e. input prices fall)

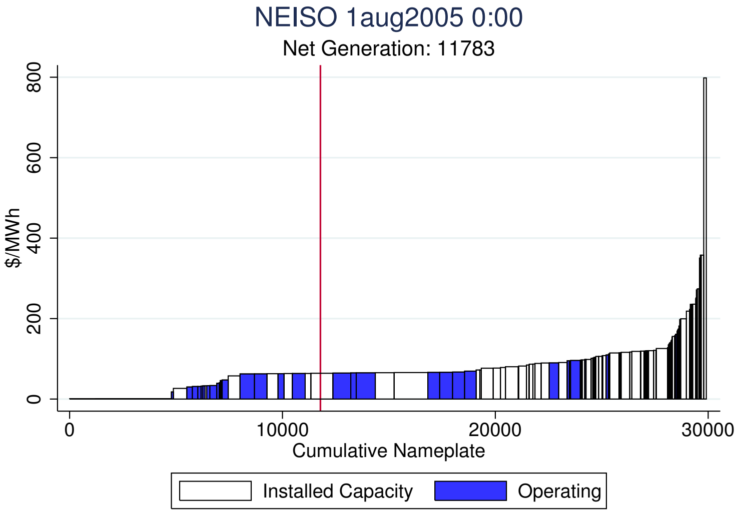
What is he going to do to solve it?

- Lot's of data
- DD research design: regulated vs. deregulated markets pre/post
- Calculate changes in merit order + gains from trade

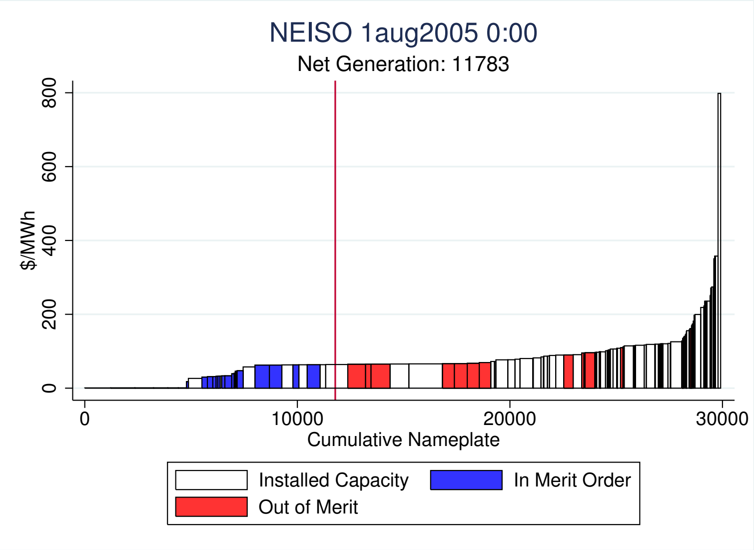
A Merit Order Example



A Merit Order Example



A Merit Order Example



Cicala (2022)

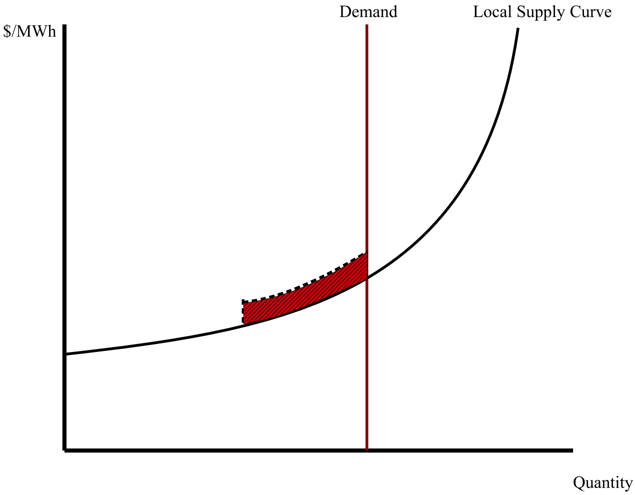
Construct hourly supply + demand of U.S. electrical grid from 1999-2012

- Data on fuel costs, capacities, heat efficiency, and operations of nearly all generating units at hourly level
- Construct power supply curves for 98 PCAs + observe units chosen to meet demand at any moment in time

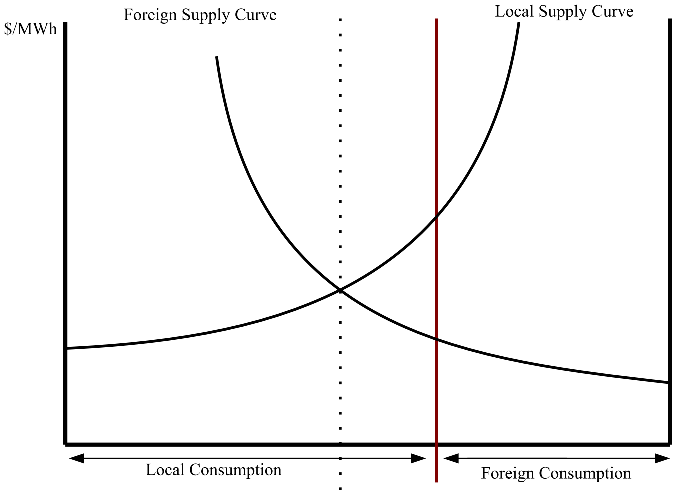
Welfare Metrics: two key welfare measures

1. "Out of merit" losses from dispatching higher marginal cost units relative to installed capacity
2. Gains from trading electricity across areas.

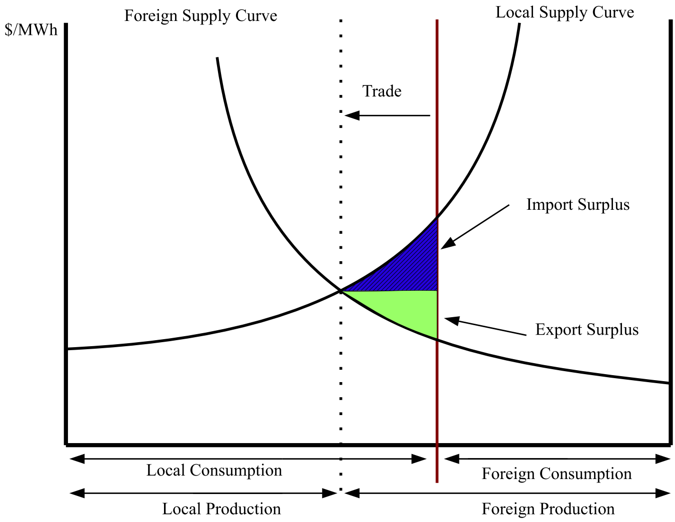
Losses from Out-of-Merit Generation



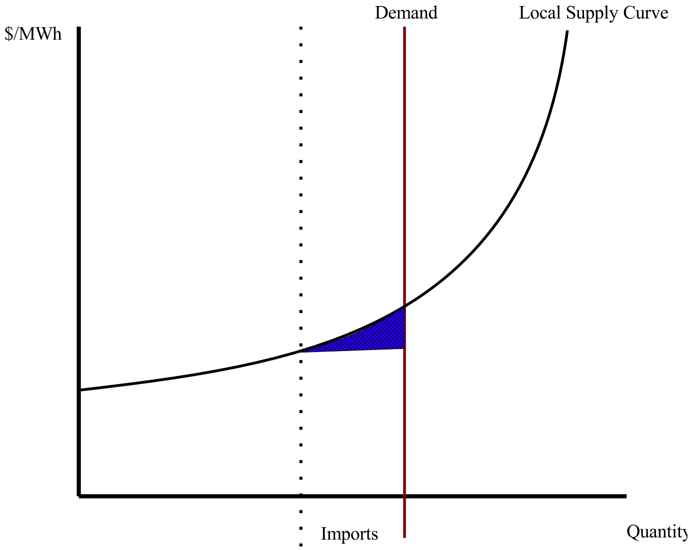
Trade: Fixed-Factor Hecksher-Ohlin Model



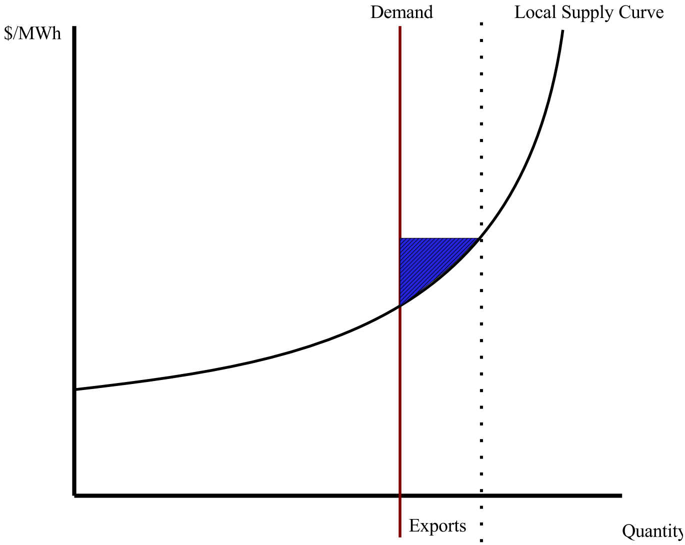
Trade: Fixed-Factor Hecksher-Ohlin Model



Local Gains from Imports



Local Gains from Exports



Cicala (2022): Research Design

Research Design: Use staggered creation of wholesale electricity markets

- Diff in diff: estimate changes in gains from trade and out of merit losses following transition to market dispatch

Challenges: changes in fuel prices change merit order curve

- Historical supply curves poor counterfactuals for merit order today

Solution: "policy function" approach

- Estimate system operators' rules for dispatching units in a given year
- Compare outcomes in following year against those predicted by the policy function

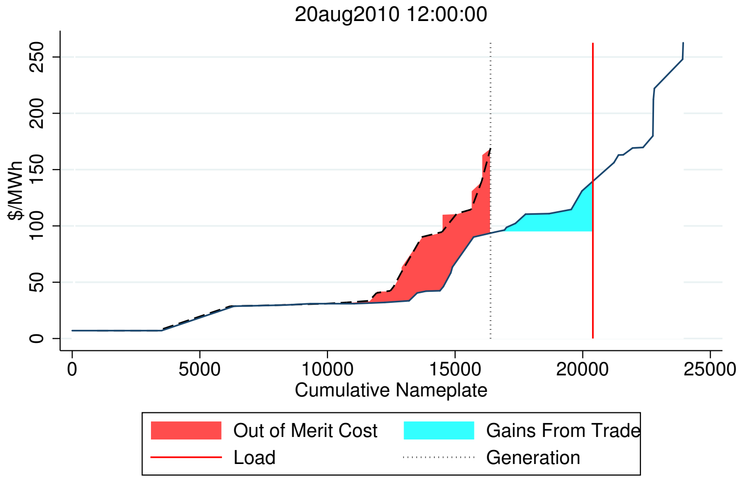
Data

- Hourly Demand (FERC-714, Regional Markets and Authorities)
- Merit Order / Supply Curve
  - Generator Nameplate (EIA-860)
  - Monthly Unit-Level Heat Rates using Net Generation (EIA-767/923)
  - Combined Cycle Heat Rates, Hydro Output (EIA-906)
  - Market Price of Fuel (Daily Regional Gas Hub prices, FERC/EIA-423/923)
  - Emissions Prices

Data

- Hourly Operational Supply Curve
  - EPA CEMS Gross Load, Emissions
  - Boiler-Generator Crosswalks (EIA-767/860)
  - Combined Cycle Scaling for Missing Cycles (EIA-906),
  - NRC Power Reactor Status Reports for Nuclear
  - USGS Stream flows
- Power Control Area Configuration as of 1999 (EPA's eGRID, FERC 714)

Measuring Welfare from Hourly Operations



Estimation Strategy

- Difference-in-Differences Design:

$$y_{pt} = \tau D_{pt} + \gamma_p + \delta_{tr} + \varepsilon_{pt}$$

- Treatment on the Treated:

$$y_{pt}(0) \perp\!\!\!\perp D_{pt} | X_i$$

Average Effect of Market Dispatch:

TABLE 2—IMPACT OF MARKET DISPATCH ON COST COMPONENTS

	(1)	(2)	(3)	(4)
Panel A. log(observed costs)				
Market dispatch	−0.085	−0.077	−0.081	−0.083
	(0.012)	(0.012)	(0.009)	(0.009)
First neighbor Market dispatch				0.027
				(0.009)
Second neighbor Market dispatch				−0.007
				(0.008)
$log(L_{pt})$		Yes	Yes	Yes
$log\left(C^{*}_{pt}(L_{pt})\right)$			Yes	Yes
Clusters	16,464	16,464	16,464	16,464
PCAs	98	98	98	98
R^2	0.946	0.955	0.963	0.963
Observations	11,996,766	11,996,766	11,996,766	11,996,766
Panel B. log(gains from trade)				
Market dispatch	0.448	0.461	0.470	0.437
	(0.071)	(0.072)	(0.066)	(0.065)
First neighbor Market dispatch				0.032
				(0.079)
Second neighbor Market dispatch				0.011
				(0.072)
$log(L_{pt})$		Yes	Yes	Yes
$log\left(C^{*}_{pt}(L_{pt})\right)$			Y[illegible]	Y[illegible]

Average Effect of Market Dispatch:

Panel C. log(out-of-merit costs)				
Market dispatch	−0.130	−0.114	−0.155	−0.180
	(0.029)	(0.028)	(0.025)	(0.026)
First neighbor				−0.008
Market dispatch				(0.032)
Second neighbor				−0.009
Market dispatch				(0.025)
log(load)		Yes	Yes	Yes
log(load merit cost)			Yes	Yes
Clusters	16,437	16,437	16,437	16,437
PCAs	98	98	98	98
R^2	0.862	0.870	0.879	0.880
Observations	11,618,837	11618,837	11,618,837	11,618,837

Notes: All specifications include PCA-month of year and region-date-hour fixed effects. Controls for the logarithm of load L_{pt} and its merit order cost $C^*_{pt}(L_{pt})$ are estimated with separate slopes by PCA-month of year. Standard errors clustered by PCA-month in parentheses.

Average Effect of Market Dispatch:

TABLE 3—IMPACT OF MARKET DISPATCH ON QUANTITIES

	(1)	(2)	(3)	(4)
Panel A. log(trade volume)				
Market dispatch	0.168	0.149	0.211	0.226
	(0.033)	(0.033)	(0.031)	(0.031)
First neighbor Market dispatch				0.044
				(0.036)
Second neighbor Market dispatch				0.009
				(0.032)
$log(L_{pt})$		Yes	Yes	Yes
$log\left(C^*_{pt}(L_{pt})\right)$			Yes	Yes
Clusters	16,464	16,464	16,464	16,464
PCAs	98	98	98	98
R^2	0.537	0.568	0.584	0.585
Observations	12,004,719	12,004,719	12,004,719	12,004,719
Panel B. log(MWh out-of-merit)				
Market dispatch	−0.072	−0.073	−0.054	−0.055
	(0.013)	(0.013)	(0.013)	(0.014)
First neighbor Market dispatch				−0.023
				(0.016)
Second neighbor Market dispatch				0.026
				(0.013)
$log(L_{pt})$		Yes	Yes	Yes
$log\left(C^*_{pt}(L_{pt})\right)$			Yes	Yes
Clusters	16,440	16,440	16,440	16,440
PCAs	98	98	98	98
R^2	0.890	0.896	0.901	0.901
Observations	11,625,543	11,625,543	11,625,543	11,625,543

Summary of Estimates

Short run estimates show substantial net improvements in allocative efficiency:

- Gains from trade in market areas: $\uparrow$ 50% (\$1B/year)
- Traded Quantities: $\uparrow$ 15%
- Out of Merit Quantities:$\downarrow$ 7%
- Out of Merit Costs: $\downarrow$ 15% (\$3B/year)

Cicala (2022): Some Caveats

- Welfare measures taking fixed capacity, costs, and patterns of demand
    - i.e. does market dispatch affect investment incentives?
- Perfectly Inelastic Demand: No Demand-Side Losses/Gains

Tons of heterogeneity in markets / transitions: What do we learn by pooling heterogeneous estimates?

- Treatment effects depend on pre-existing institutions and/or rules of the markets implemented
- Might be useful to think about this heterogeneity more formally

Some Other Approaches for Estimating Costs

Asset Market Approach: stock prices for publicly traded firms as a function of various deregulatory announcements

- Rose (1985): Deregulation in trucking
- Meng (2017): Cap and Trade + Prediction Markets
- Bushnell, Chong, and Mansur (2013): EU ETS price capitalization

Shapiro and Walker (2021): Is Air Pollution Reg. Too Stringent?

- **Optimal corrective taxation: marginal benefits = marginal costs**
  - Often hard to measure total costs and benefits, let alone marginal
  - Crime, innovation, smoking, ...
- **Air pollution: important externality**
  - 5% of premature US mortality from one air pollutant (Dominici et al. 2014)
  - Ambient levels have fallen dramatically
  - Increasing marginal costs of abatement: when exceed marginal benefits?

Figure: $PM_{2.5}$

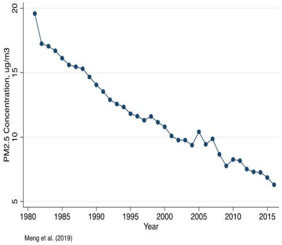
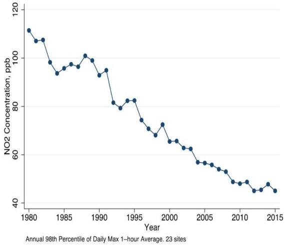


Figure: NO_2



Our Approach: Background

- **1970 Clean Air Act forbids emission increases from polluted counties**
  - Entrants: offset pollution with decrease from an incumbent
  - Entrants pay incumbents, can be tens of millions of $
  - Incumbents abate or close
  - Policy applies to "stationary" sources (not cars)
- **Pollution offset markets**
  - Decentralized, bilateral markets
  - Separate markets for each nonattainment area$\times$pollutant
  - Examples: particulate matter in SF Bay Area; nitrogen oxides in Houston
- **Offsets common**
  - 600 markets, 65 percent of US population
  - Other offset markets: Australia, Brazil, Canada, EU, many enviro. goods

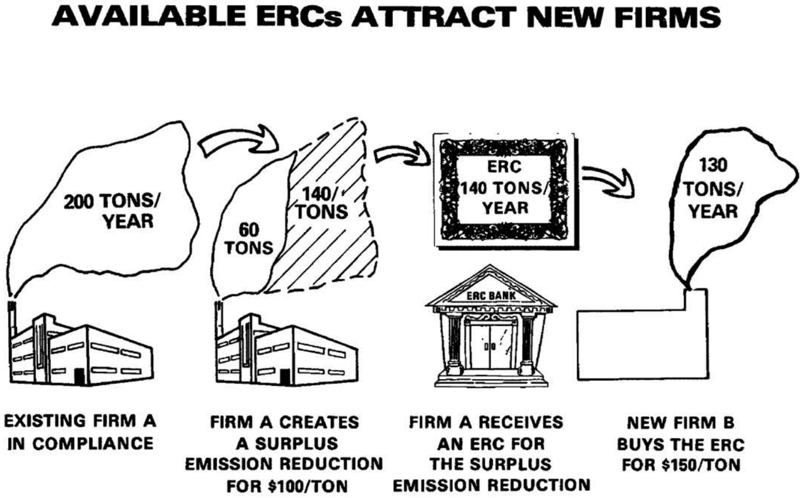
Our Approach: Intuition

- **Offset prices reflect marginal cost of abatement**
  - Entrants, incumbents: choose $\text{MC}_{\text{abatement}} = \text{offset price}$
  - Theory: planner chooses $\text{MB}_{\text{abatement}} = \text{offset price}$
  - $\text{MB}_{\text{abatement}}$ represents health, other benefits of cleaner air
- **Simple test**
  - If offset prices $> \text{MB}_{\text{abatement}}$, regulation too stringent
  - If offset prices $< \text{MB}_{\text{abatement}}$, regulation too lenient

What is New Here

- **Method to measure marginal costs of pollution abatement**
  - Engineering estimates: miss economic costs (USEPA 2006, 2007; Fowlie 2010)
  - Cost functions: mostly sulfur-coal (Gollop, Roberts 1985; Carlson et al. 2000)
  - Diff-in-diff: total costs (Greenstone 2002; Ryan 2012; Walker 2013)
  - Cap and trade: few markets (Fowlie et al. 2012; Deschenes et al. 2017)
- **Comprehensive analysis of air pollution offset markets**
  - Mostly policy descriptions (Dudek, Palmisano 1988; Foster, Hahn 1995)
- **Revealed preference marginal abatement costs for air pollution**
  - First estimate for many pollutants$\times$markets$\times$years

Offset Market Design



Offset Market Design

The State of Texas

TEXAS COMMISSION ON ENVIRONMENTAL QUALITY

Certificate Number: 2697

Number of Credits: 21.8 tpy VOC

Emission Reduction Credit Certificate

This certifies that
Scan-Pac Mfg., Inc.
31502 Sugar Bend Drive
Magnolia, Texas 77355

is the owner of 21.8 tons per year of volatile organic compound (VOC) emission reduction credits established under the laws of the State of Texas, transferable only on the books of the Texas Commission on Environmental Quality, by the holder hereof in person or by duly authorized Attorney, upon surrender of this certificate.

The owner of this certificate is entitled to utilize the emission credits evidenced herein for all purpose authorized by the laws and regulations of the State of Texas and is subject to all limitations prescribed by the laws and regulations of the State of Texas. This certificate may be used for credit in the following counties:

Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller

Effective Date of the Emission Reduction: May 15, 2013
Regulated Entity Number: RN100219989
County of Generation: Montgomery

Generator Certificate: Original

- Scan-Pac, a Houston manufacturing plant, built a thermal oxidizer
- Decreased VOC emissions by 21.8 tons per year, received this offset
- Sold this offset to Enterprise Products, an oil company, for $3.6 million

Data

- **Pollution offset markets**
  - Prices and quantities from 16 states + Washington D.C.
  - California and Texas have richer data on individual transactions
  - Texas: seller, buyer identity, attributes, list of potential sellers

Offset Market Design: Market Locations

Figure: Ozone

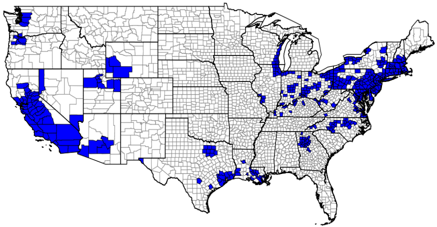


Figure: Particulate matter

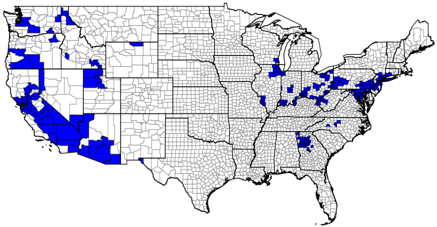
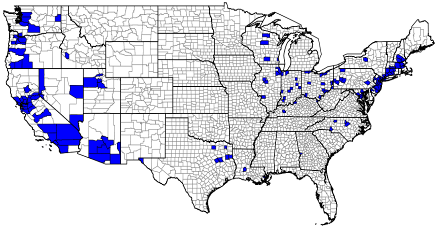


Figure: Other pollutants



Data

- **Marginal benefits of abatement**
    - =Marginal damages of emissions
    - AP3 model (Clay et al. 2019, Holland et al. forthcoming)
    - Precursors: AP2, APEEP (Muller and Mendelsohn 2009, 2012 AER)
        - Used in NRC (2010); Muller et al. (AER 2011); Holland et al. (AER 2016); Gowrisankaran et al. (JPE 2016); Fowlie et al. (QJE 2018)
    - Adult and infant mortality, morbidity, crop and timber yields, recreation visibility, depreciation of materials (e.g., steel in buildings), lost recreation

Have also explored sensitivity to using 2 other leading integrated assessment models for estimating marginal benefits

- InMAP and EASIUR

Data: Marginal Benefits of Abatement

Figure: Nitrogen oxides

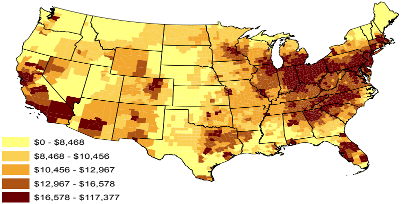


Figure: Particulate matter

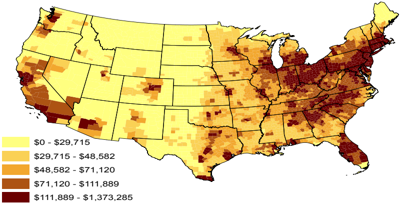
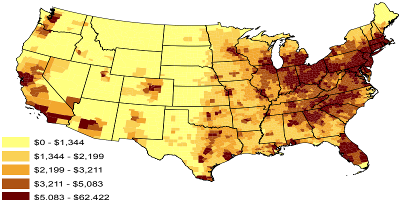


Figure: Volatile organic compounds



Interpreting Offset Prices: Planner

- Planner's problem:
$$min_X \sum_i [C_i(X_i) + T(X_i) + D_i(X_i)]$$
- X_i emissions from source i.
- $C_i(\cdot)$ abatement cost function: all non-transaction costs
- $T(X_i)$ Transaction costs: search and matching, uncertainty, etc.
- $D_i(X_i)$ Pollution damages: mortality, morbidity, etc.

Interpreting Offset Prices: Planner

- Planner's problem:

$$min_X \sum_i [C_i(X_i) + T(X_i) + D_i(X_i)]$$

- FOC:

$$-\frac{\partial C_i(X_i)}{\partial X_i} - \frac{\partial T(X_i)}{\partial X_i} = \frac{\partial D_i(X_i)}{\partial X_i}$$

  - First term: marginal pollution abatement cost
  - Second term: marginal transaction cost
  - Third term: marginal pollution damages

- Textbook rule: equate marginal costs of abatement to marginal benefits of abatement
- Here: transaction a second component of costs
- Intuition: as transaction costs increase, firms optimally abate less
  - Ironic: some environmental groups prefer mechanisms with high transaction costs (command and control), but they decrease optimal abatement

Interpreting Offset Prices: Decentralize/Firms

- Firm's problem:

$$max_{X_i} P_Y Y(X_i) - A_i(X_i) - T_i(X_i) - PX_i$$

  - Output $Y(X_i)$
  - Output price P_y
  - Abatement costs $A_i(X_i)$
  - Transaction costs $T_i(X_i)$
  - Offset price P

Interpreting Offset Prices: Decentralize/Firms

- Firm's problem:

$$max_{X_i} P_Y Y(X_i) - A_i(X_i) - T_i(X_i) - PX_i$$

  - Output $Y(X_i)$
  - Output price P_y
  - Abatement costs $A_i(X_i)$
  - Transaction costs $T_i(X_i)$
  - Offset price P

- FOC:

$$P_Y \frac{\partial Y(X_i)}{\partial X_i} - \frac{\partial A_i(X_i)}{\partial X_i} - \frac{\partial T_i(X_i)}{\partial X_i} = P$$

- Defining abatement costs as $-\frac{\partial C_i(X_i)}{\partial X_i} = P_Y \frac{\partial Y(X_i)}{\partial X_i} - \frac{\partial A_i(X_i)}{\partial X_i}$, FOC becomes

$$-\frac{\partial C_i(X_i)}{\partial X_i} - \frac{\partial T_i(X_i)}{\partial X_i} = P$$

Interpreting Offset Prices: Theory

- Firm's problem:

$$max_{X_i} P_Y Y(X_i) - A_i(X_i) - PX_i - T_i(X_i)$$

- FOC:

$$-\frac{\partial C_i(X_i)}{\partial X_i} - \frac{\partial T_i(X_i)}{\partial X_i} = P$$

- Firm abates until abatement + transaction costs equal offset prices

Interpreting Offset Prices: Theory

- Planner's FOC:

$$-\frac{\partial C_i(X_i)}{\partial X_i} - \frac{\partial T(X_i)}{\partial X_i} = \frac{\partial D_i(X_i)}{\partial X_i}$$

- Firm's FOC:

$$-\frac{\partial C_i(X_i)}{\partial X_i} - \frac{\partial T_i(X_i)}{\partial X_i} = P$$

- Combining,

$$P = \frac{\partial D_i(X_i)}{\partial X_i}$$

Interpreting Offset Prices: Theory

- Planner's FOC:

$$-\frac{\partial C_i(X_i)}{\partial X_i} - \frac{\partial T(X_i)}{\partial X_i} = \frac{\partial D_i(X_i)}{\partial X_i}$$

- Firm's FOC:

$$-\frac{\partial C_i(X_i)}{\partial X_i} - \frac{\partial T_i(X_i)}{\partial X_i} = P$$

- Combining,

$$P = \frac{\partial D_i(X_i)}{\partial X_i}$$

- At optimum, offset price = pollution damages
- Similar to standard result for cap-and-trade, but with frictions
  - If offset price > marginal benefits of abatement, offsets more expensive than optimal
  - If offset prices < marginal benefits of abatement, offsets less expensive than optimal

Constraints

Results: Offset Prices / Marginal Benefits of Abatement

Table 3—Ratio of Offset Prices to Marginal Benefits of Abatement by Region, 2010-2019

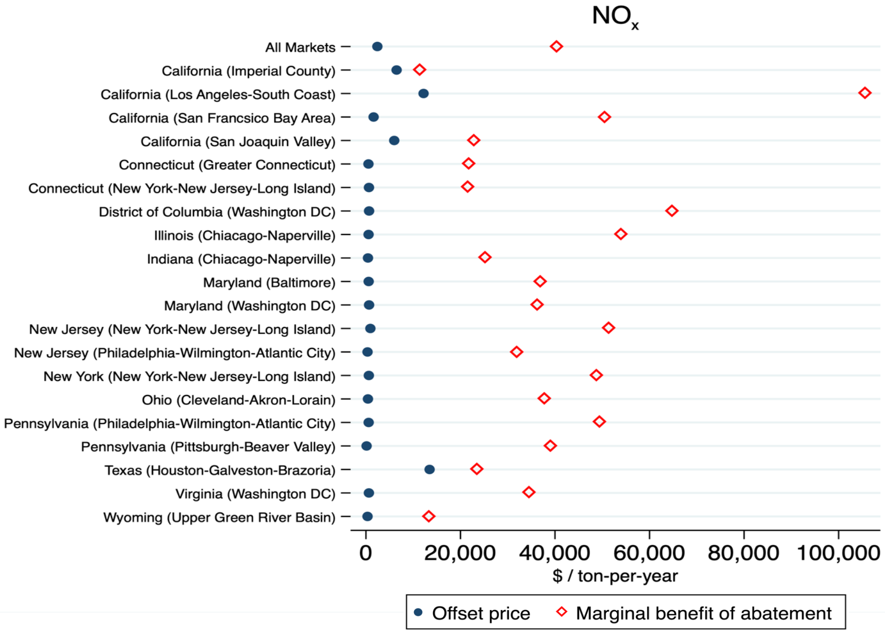
	NO_x		VOCs	
	(1)		(2)	
Panel A. National				
1. Offset prices / marginal benefits of abatement	0.06	0.08	0.14	0.11
2. Mean pollution offset prices (per ton of emissions)	$2,416	$4,058	$2,798	$2,213
3. Mean pollution marginal benefits of abatement	$40,501	$51,466	$20,620	$20,602
Weight	Tons	Population	Tons	Population

Results: Offset Prices / Marginal Benefits of Abatement

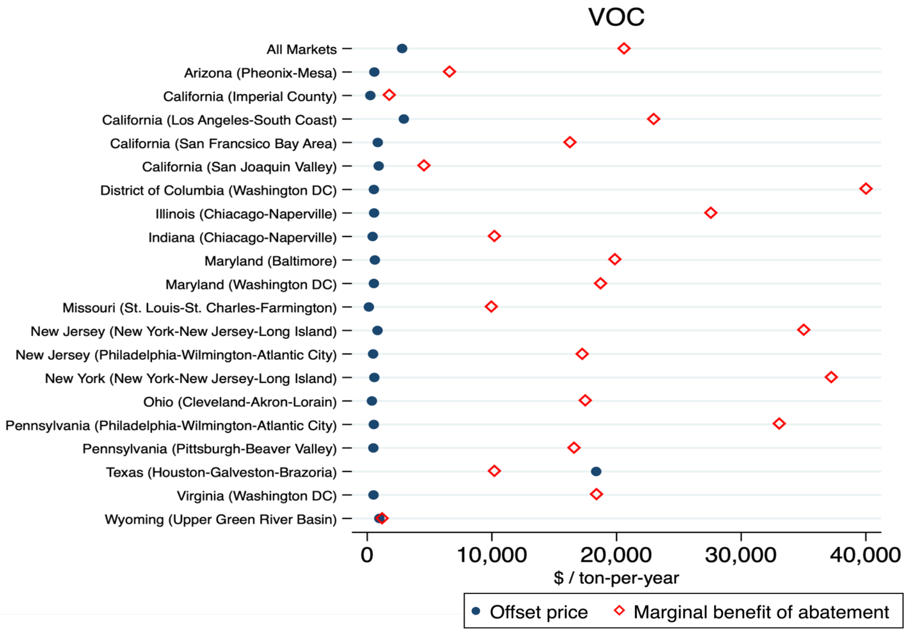
Table 3—Ratio of Offset Prices to Marginal Benefits of Abatement by Region, 2010-2019

	NO_x		VOCs	
	(1)		(2)	
Panel B. Northeast				
1. Offset prices / marginal benefits of abatement	0.01	0.01	0.02	0.02
2. Mean pollution offset prices (per ton of emissions)	$554	$610	$607	$603
3. Mean pollution marginal benefits of abatement	$44,938	$44,166	$29,319	$32,478
Panel C. South				
1. Offset prices / marginal benefits of abatement	0.25	0.16	0.77	0.42
2. Mean pollution offset prices (per ton of emissions)	$7,427	$4,740	$10,198	$5,602
3. Mean pollution marginal benefits of abatement	$29,481	$28,805	$13,264	$13,277
Panel D. West				
1. Offset prices / marginal benefits of abatement	0.12	0.11	0.13	0.14
2. Mean pollution offset prices (per ton of emissions)	$4,118	$8,020	$1,443	$2,230
3. Mean pollution marginal benefits of abatement	$35,737	$72,414	$10,703	$15,488
Panel E. Midwest				
1. Offset prices / marginal benefits of abatement	0.01	0.01	0.02	0.02
2. Mean pollution offset prices (per ton of emissions)	$502	$517	$425	$448
3. Mean pollution marginal benefits of abatement	$44,503	$48,581	$19,734	$22,215
Weight	Tons	Population	Tons	Population

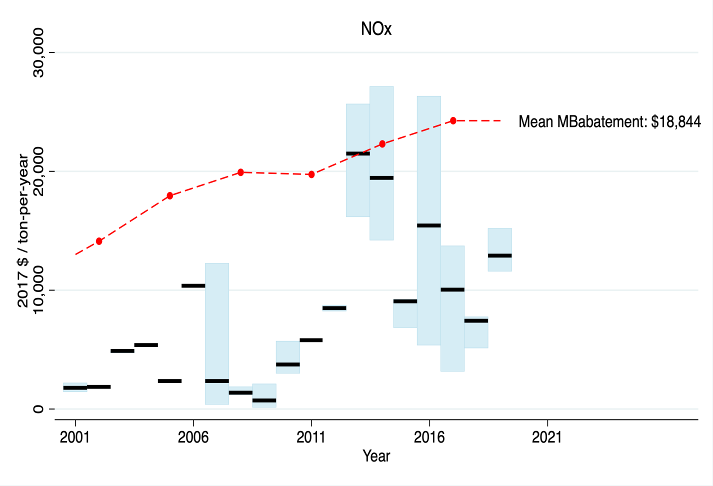
Results: Offset Prices / Marginal Benefits of Abatement



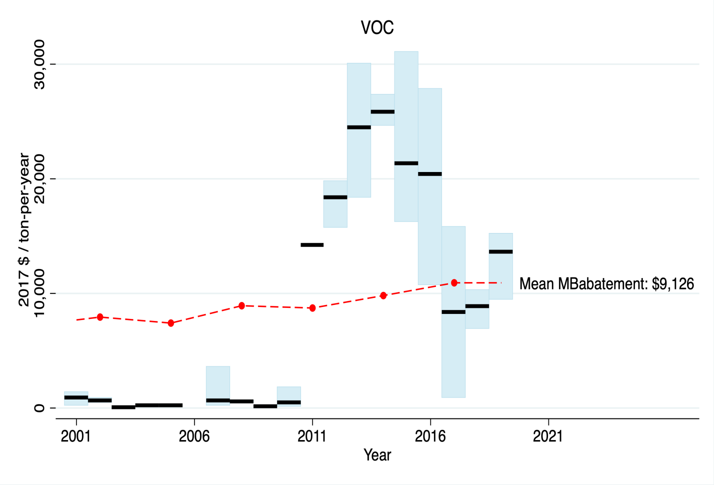
Results: Offset Prices / Marginal Benefits of Abatement



Prices Versus Quantities: Offset Prices / Marginal Benefits of Abatement: Houston NO_x

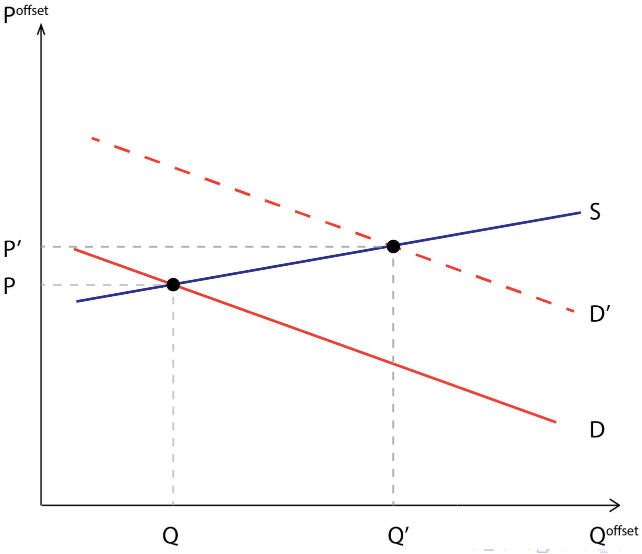


Prices Versus Quantities: Offset Prices / Marginal Benefits of Abatement: Houston VOCs



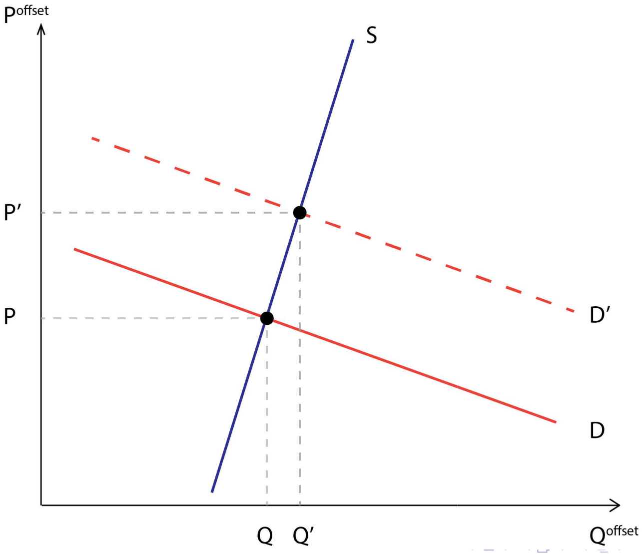
Price Volatility: Interpretation

Figure: Offset Market Equilibrium: Flat Supply



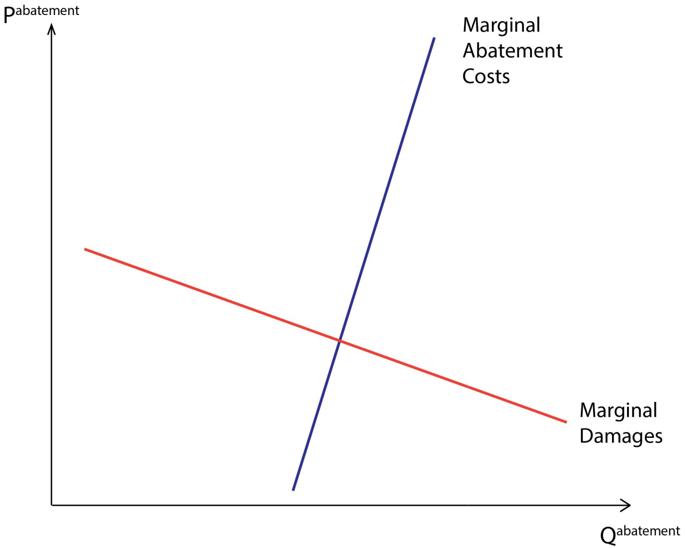
Price Volatility: Interpretation

Figure: Offset Market Equilibrium: Steep Supply



Price Volatility: Interpretation

Figure: Abatement Market Equilibrium



Price Volatility: Interpretation

- Offset markets: quantity policy
- Planner prefers price policy if marginal abatement cost curve steeper than marginal benefits of abatement curve (Weitzman 1974)
  - Volatility of shocks affects magnitude of welfare gain, but relative slopes determines ranking
- Marginal benefits of abatement curve: believed to be relatively flat for moderate emission changes (Apte et al. 2015)
- Marginal abatement cost curve: steeply sloped?

Conclusions

- Designing efficient corrective policy requires measuring marginal costs and benefits
  - Usually hard
  - Pollution: historic advances in measuring MB, less for measuring MC
  - Offsets: ability to measure marginal costs of abatement for different locations, pollutants, and years

Estimating Transitional Costs (Walker 2012)

What is the question, and why is it interesting?

- Shifting production from dirty to cleaner production necessitates reallocation costs for workers/firms
- How large are these transitional costs born for workers in affected firms (e.g., wage losses due to job loss)

Why is the existing research crappy, <u>nonexistent</u>, and/or unresolved?

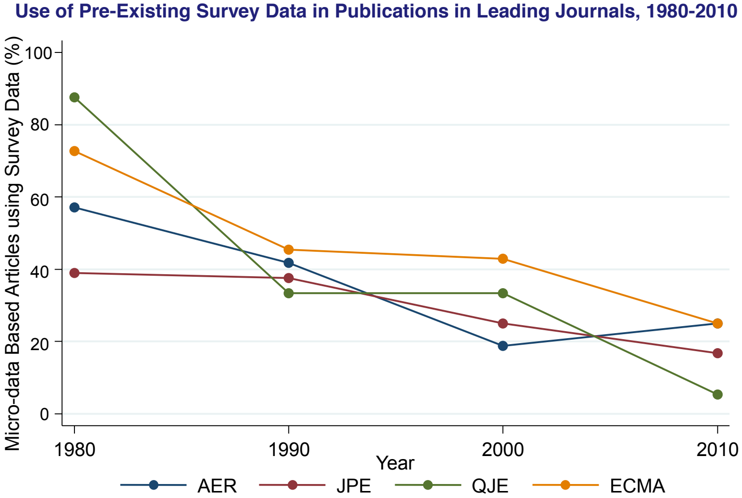
- Prior research on environmental regulation examines employment effects or plant entry/exit with the implicit notion that these are costly
  e.g. Henderson (1996), Greenstone (2002), List et al. (2003), Walker (2011)
- No work that explores the costs and incidence of environmental regulations for workers in affected industries.

What is he going to do to solve it?

- Longitudinal linked worker-firm data to follow workers over time + across jobs
- Research design: county-industry-year variation in Clean Air Act stringency

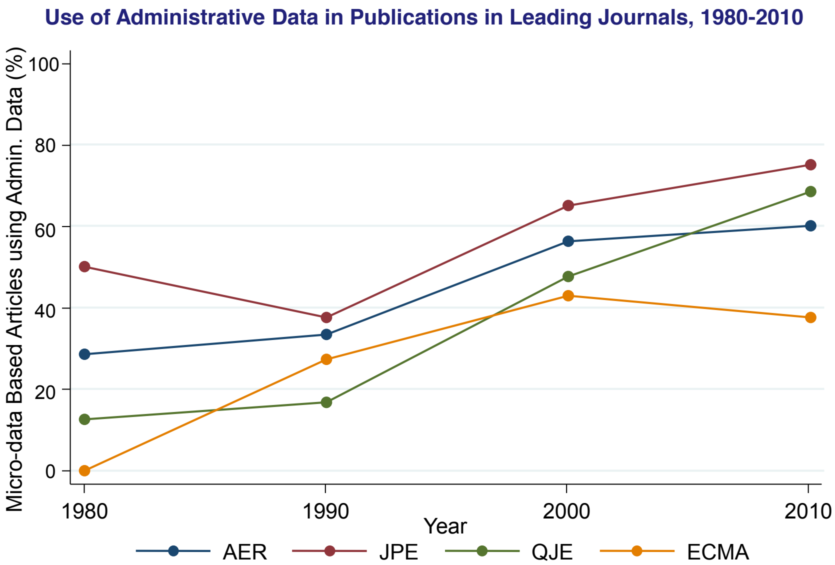
Sidebar: Administrative Data, Federal Research Data Center

Chetty (2012) "The Transformative Potential of Administrative Data..."



Note: "Pre-existing survey" datasets refer to micro surveys such as the CPS or SIPP and do not include surveys designed by researchers for their study. Sample excludes studies whose primary data source is from developing countries.

Chetty (2012) "The Transformative Potential of Administrative Data..."



Note: "Administrative" datasets refer to any dataset that was collected without directly surveying individuals (e.g., scanner data, stock prices, school district records, social security records). Sample excludes studies whose primary data source is from developing countries.

What are the Benefits of Administrative Data?

1. **Higher quality information: little missing data or attrition**
   - CPS (i.e. publicly available data) non-response rate now 31% for income
2. **Very large sample sizes: 2,000 times the size of the CPS**
   - Can develop new non-parametric, quasi-experimental research designs
3. **Longitudinal tracking over long periods**
   - Plant level panel datasets, longitudinal earnings records, etc...
4. **Linkages to outside datasets create additional opportunities**
   - Spatial linkages using GIS, person linkages through SSN or birthdate/name, plant/firm linkages through string matching

Administrative Data in the U.S.

Demand for admin. data has led to "offshoring" of U.S. research

- Population registers in Sweden, Austria, Germany, Norway, Denmark
- Plant/firm level panels in numerous countries: Germany, Chile, France, India, Mexico, Romania, Slovenia, and Spain

Census RDC provides avenue for doing research using US admin data

What Data Exists in the RDC?

Economic Data: Firms and Establishments

- Census of Manufacturers, Annual Survey of Manufacturers, Commodity Flow Survey, etc...

Demographic Data: Households and Individuals

- ACS, Census, CPS (with geography)

Mixed data: Both individuals and firms "linked worker-firm data"

- Longitudinal Employer Household Dynamics File (LEHD)

Options to create your own linkages:

- e.g. Plant level data from outside sources (Walker 2012, Greenstone, Hornbeck and Moretti 2011)

Summary: Recent Insights from Administrative Data In the US

Endless Possibilities and Lots of "Low Hanging Fruit"

- Lots of new, underutilized datasets
- Temporal and spatial "resolution" provide lots of possibilities for unique research designs
- Sample sizes often conducive to quasi-experimental regression techniques (e.g. RD).
- New firm R&D surveys, commodity flow survey, Longitudinal Firm Trade Transactions Database (LFTTD)

So, What's the Catch?

So, What's the Catch?

The Proposal/Application/Review Process Takes Time

1. Research Question
2. Write Proposal (estimate 1-4 months)
    - Contact and work with Census administrator
    - Be broad but focused
    - Need to show some benefit to Census
3. Wait (estimate 6 months - 2 years)
    - Census Review (estimate 6 months)
    - NCHS Review ($<$ 6 months)
    - IRS Review (???)
4. Special Sworn Status (estimate 2-3 months)
5. Analysis/Writeup (???)

So, What's the Catch?

Census bureaucracy can be frustrating

- Incentives?

You have very few "rights" as a researcher using this data

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- Incentives?

You have very few "rights" as a researcher using this data

Three "salient" examples:

1. Data access can be suspended (e.g. government shutdown/COVID)
2. Data may not be available even once your project is approved
3. Data access can be taken away (rare but happens)...

V. Supremacy of Census Bureau and Data Supplier Administrative Requirements

This computer account and data request does not supercede the administrative procedures and requirements of the Census Bureau and other data providing agencies. During the course of this project, changes may occur in administrative procedures and/or requirements of the Census Bureau and/or data providing agencies governing the use of the data provided to the researcher. In addition, changes may occur in the availability of data under both the governing MOU's in existence as of the date of this account and data request, and related Memorandum of Understanding (MOU) that come into existence during the course of the project. In such cases, relevant portions of this document may no longer be valid and shall be superceded by new language in order to accommodate administrative requirements of the Census Bureau and/or data providing agencies.

Estimating Transitional Costs (Walker 2012)

Government intervention into markets is controversial

- e.g. trade policy, environmental policy

Interaction between policy and job creation/destruction is politically salient

OPINION | JULY 26, 2011

The Latest Job Killer From the EPA THE WALL STREET JOURNAL.

The agency's ozone rule will be the most expensive in history—and isn't required by law.

September 4, 2011

A Debate Arises on Job Creation and Environment

By MOTOKO RICH and JOHN BRODER

Do environmental regulations kill jobs?

The New York Times

Jobs and capital are rarely "lost" or made obsolete.

- Factors of production generally become employed in another capacity.

The Costs of Worker Reallocation

Benefit-Cost Analysis in Environmental, Health, and Safety Regulation: A Statement of Principals

Regardless of the size of the employment effect, the appropriate measure of regulatory costs is the transition costs of employees who are forced to switch jobs because of the regulation. (Arrow et al. 1996).

Prior research on environmental regulation examines employment effects or plant entry/exit with the implicit notion that these are costly

- e.g. Henderson (1996), Greenstone (2002), List et al. (2003), Walker (2011)

No work that explores the costs and incidence of environmental regulations for workers in these industries.

Transitional Costs of Workforce Reallocation

This Paper:
Explores the reallocative costs of environmental policy for workers in these newly regulated plants and industries.

- Develop a new approach to characterizing the costs and consequences of local labor market adjustment to sector specific shocks
- Longitudinal linked worker-firm data to follow workers over time and across firms
- Incorporate two important features of labor market adjustment:
  1. Equilibrium wage changes *within* a firm/sector
  2. Costly worker transitions *across* firms/sectors

Transitional Costs of Workforce Reallocation

Research Questions:

1. How large are the reallocative costs of environmental policy for workers in newly regulated sectors?
2. Along what margins are these costs important?

Implementation:

- Detailed employment/earnings histories from 3 million workers and follow them over time from 1990-2000

Empirical Framework

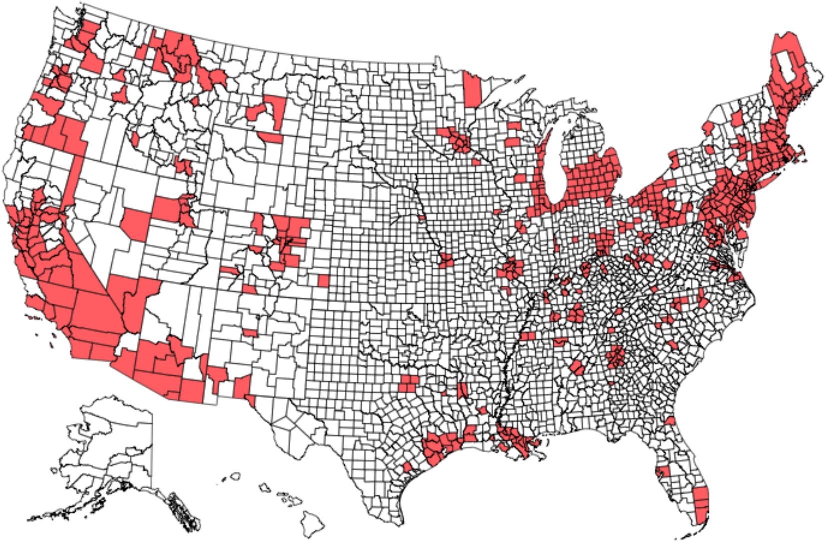
1. Exploit panel variation stemming from the 1990 Clean Air Act Amendments — i.e. county$\times$sector$\times$year regulation
2. Follow cohorts of workers irrespective of future jobs/locations

Clean Air Act as the Basis for a Research Design

Polluting firms in **nonattainment counties** are regulated

1. Only some counties are in nonattainment in a given year
   - Nationwide or industry wide controls

Nonattainment Counties in 1991



NOTE: Figure shows county nonattainment designation for any pollutant. Source EPA.

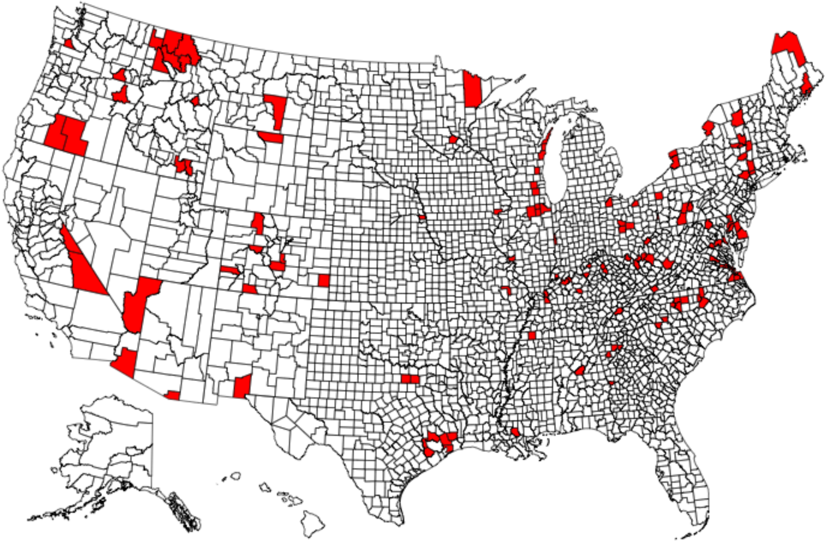
Clean Air Act as the Basis for a Research Design

Polluting firms in **nonattainment counties** are regulated

1. Only some counties are in nonattainment in a given year
   - Nationwide or industry wide controls
2. Counties enter/exit nonattainment based on ambient pollution levels
   - Pre-post comparisons within counties/firms/workers

Clean Air Act Amendments of 1990: New Nonattainment Counties

Clean Air Act Amendments created new and stronger pollution standards



Clean Air Act as the Basis for a Research Design

Polluting firms in **nonattainment counties** are regulated

1. Only some counties are in nonattainment in a given year
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2. Counties enter/exit nonattainment each year based on pollution levels
   - Pre-post comparisons within counties/firms/workers
3. Only polluting firms are regulated in a county
   - Facilitates within county comparisons of regulated/unregulated firms
   - Control for unobserved local economic conditions

Clean Air Act as the Basis for a Research Design

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    - Pre-post comparisons within counties/firms/workers

3. Only polluting firms are regulated in a county
    - Facilitates within county comparisons of regulated/unregulated firms
    - Control for unobserved local economic conditions

Baseline Identification Assumption

- No unobserved shocks to *polluting sectors* of counties that *switch* into nonattainment in years *after* nonattainment went into place

Data

Longitudinal Employer Household Dynamics (LEHD)

- Longitudinally linked worker-firm data for United States
- Begin with 4 States: MD, IL, WA, WI (i.e. states with 1990 data)
- Construct job/earnings histories for 3m workers from 1990-2003.
  - Able to follow workers across jobs/state lines

Longitudinal Business Database (LBD)

- Longitudinal establishment level database
- Universe of establishments in United States 1985-2005
- Information on industry, entry date, exit date, plant age, payroll, and employment at annual establishment level.

Data

EPA: Air Facility System (AFS) Regulatory Data

- Plant level database detailing those plants covered under the CAA nonattainment State Implementation Plans
- Name and address matching algorithms connect this to establishment level Census data

EPA Greenbook: County Level Nonattainment Designations

- County$\times$Year$\times$Pollutant Nonattainment Designations
- 1985-2005

Empirical Framework: Triple Difference

Polluting Sectors (P_s)/Switching county (N_c)/After CAAA ($\tau_t \geq 0$)

$$Y_{cst} = \eta_1 \underbrace{\left[P_s \times N_c \times 1(\tau_t \geq 0)\right]}_{\text{Regulation Indicator}} + \rho_{cs} + n_{ct} + p_{st} + \gamma_t + \epsilon_{cst}$$

ρ_{cs}: County×Sector FE n_{ct}: Nonattain×Year FE
p_{st}: Polluter×Year FE γ_t: Year FE

Identifying Assumption:

- No unobserved, county-level economic shock to polluters in newly regulated counties in years after policy (i.e. common trends)

Testing Assumptions:

- Examine trends in years prior to change
- Test for general equilibrium effects using more aggregate variation

Empirical Framework: Exploring Regulatory Dynamics

Polluting Sectors (P_s)/Switching county (N_c)/After CAAA ($\tau_t \geq 0$)

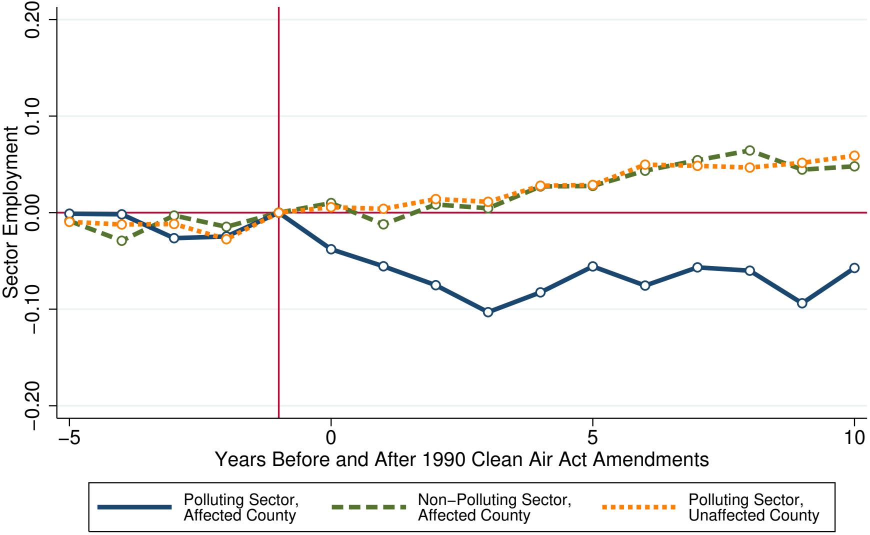
$$Y_{cst} = \sum_{k=-5}^{10} \eta_1^k [P_s \times N_c \times 1(\tau_t = k)] + \rho_{cs} + n_{ct} + p_{st} + \gamma_t + \epsilon_{cst}$$

Generalized Triple Difference Estimator:

- Allow regulatory effect to evolve smoothly over time

Primary Estimation Equation

Results: Regulation and Sector Level Employment



Empirical Framework: A Cohort Based Approach

Divide workers into "cohorts" based on "pre-regulation" county$\times$sectors.

- Sectors are defined as polluting or non-polluting

Follow these "cohorts" over time

- Workers can move jobs but still contribute to cohort wage

Polluting Cohort (P_s)/Switching county (N_c)/After CAAA ($\tau_t \geq 0$)

$$w_{cst} = \sum_{k=0}^{10} \eta_1^k [P_s \times N_c \times 1(\tau_t = k)] + \rho_{cs} + n_{ct} + p_{st} + e_{cst} + \gamma_t + \epsilon_{cst}$$

Results: Earnings Loss of Workers in Regulated, Polluting Firms

	Baseline				Levels	Zero Earnings
	(1)	(2)	(3)	(4)	(5)	(6)
Regulation (t+0)	-0.037	-0.029	-0.030	-0.025		
	(0.029)	(0.022)	(0.018)	(0.021)		
Regulation (t+1)	-0.064*	-0.058**	-0.059**	-0.052*		
	(0.033)	(0.026)	(0.025)	(0.028)		
Regulation (t+2)	-0.056**	-0.050***	-0.051***	-0.048*		
	(0.024)	(0.019)	(0.018)	(0.025)		
Regulation (t+3)	-0.047***	-0.042***	-0.043***	-0.039**		
	(0.015)	(0.012)	(0.013)	(0.018)		
Regulation (t+4)	-0.052***	-0.048***	-0.048**	-0.042*		
	(0.016)	(0.018)	(0.020)	(0.023)		
Regulation (t+5)	-0.022	-0.019	-0.019	-0.013		
	(0.022)	(0.019)	(0.018)	(0.021)		
N	6847	6847	6847	6847		
Cohort FE	X	X	X	X		
Experience		X	X	X		
County Trends			X			
County×Year FE				X		

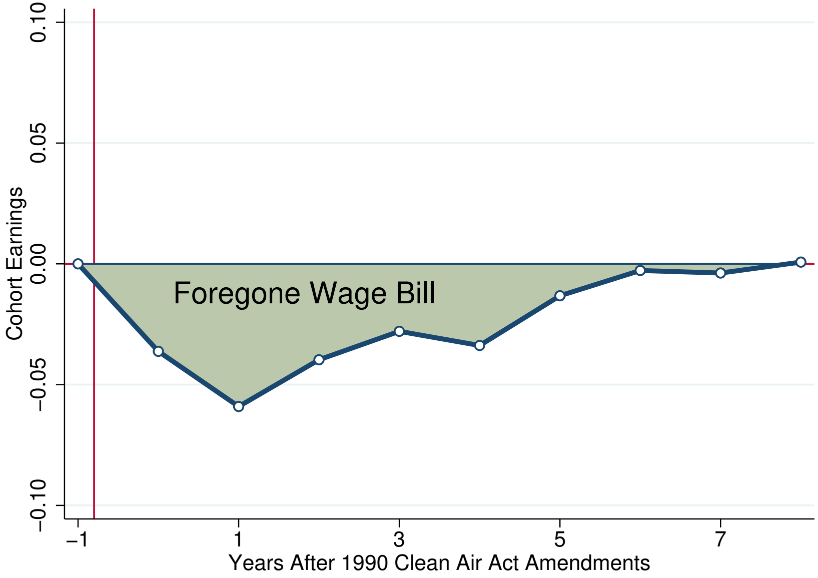
Results: Earnings Loss of Workers in Regulated, Polluting Firms

	Baseline				Levels	Zero Earnings
	(1)	(2)	(3)	(4)	(5)	(6)
Regulation (t+0)	-0.037	-0.029	-0.030	-0.025	-1045.38	
	(0.029)	(0.022)	(0.018)	(0.021)	(812.10)	
Regulation (t+1)	-0.064*	-0.058**	-0.059**	-0.052*	-1889.78*	
	(0.033)	(0.026)	(0.025)	(0.028)	(1071.37)	
Regulation (t+2)	-0.056**	-0.050***	-0.051***	-0.048*	-1898.65**	
	(0.024)	(0.019)	(0.018)	(0.025)	(819.29)	
Regulation (t+3)	-0.047***	-0.042***	-0.043***	-0.039**	-1740.67***	
	(0.015)	(0.012)	(0.013)	(0.018)	(589.96)	
Regulation (t+4)	-0.052***	-0.048***	-0.048**	-0.042*	-1992.42**	
	(0.016)	(0.018)	(0.020)	(0.023)	(829.28)	
Regulation (t+5)	-0.022	-0.019	-0.019	-0.013	-785.76	
	(0.022)	(0.019)	(0.018)	(0.021)	(703.65)	
N	6847	6847	6847	6847	6847	
Cohort FE	X	X	X	X	X	
Experience		X	X	X	X	
County Trends			X		X	
County×Year FE				X		

Results: Earnings Loss of Workers in Regulated, Polluting Firms

	Baseline				Levels	Zero Earnings
	(1)	(2)	(3)	(4)	(5)	(6)
Regulation (t+0)	-0.037	-0.029	-0.030	-0.025	-1045.38	-1202.74
	(0.029)	(0.022)	(0.018)	(0.021)	(812.10)	(831.06)
Regulation (t+1)	-0.064^{*}	-0.058^{**}	-0.059^{**}	-0.052^{*}	-1889.78^{*}	-1989.91^{*}
	(0.033)	(0.026)	(0.025)	(0.028)	(1071.37)	(1185.02)
Regulation (t+2)	-0.056^{**}	-0.050^{***}	-0.051^{***}	-0.048^{*}	-1898.65^{**}	-2148.54^{**}
	(0.024)	(0.019)	(0.018)	(0.025)	(819.29)	(848.44)
Regulation (t+3)	-0.047^{***}	-0.042^{***}	-0.043^{***}	-0.039^{**}	-1740.67^{***}	-2015.65^{***}
	(0.015)	(0.012)	(0.013)	(0.018)	(589.96)	(650.99)
Regulation (t+4)	-0.052^{***}	-0.048^{***}	-0.048^{**}	-0.042^{*}	-1992.42^{**}	-2039.14^{***}
	(0.016)	(0.018)	(0.020)	(0.023)	(829.28)	(750.97)
Regulation (t+5)	-0.022	-0.019	-0.019	-0.013	-785.76	-785.56
	(0.022)	(0.019)	(0.018)	(0.021)	(703.65)	(734.25)
N	6847	6847	6847	6847	6847	6847
Cohort FE	X	X	X	X	X	X
Experience		X	X	X	X	X
County Trends			X		X	X
County $\times$ Year FE				X		

Results: Earnings Loss of Workers in Regulated, Polluting Firms



Results: Earnings Loss of Workers in Regulated, Polluting Firms

Total foregone wage bill ≈ $9 billion

	Baseline				Levels	Zero Earnings
	(1)	(2)	(3)	(4)	(5)	(6)
9 Year PDV	-0.261**	-0.229**	-0.233***	-0.201*	-8477.32**	-9902.34**
	(0.120)	(0.089)	(0.085)	(0.105)	(3811.51)	(3841.66)
N	6847	6847	6847	6847	6847	6847
Cohort FE	X	X	X	X	X	X
Experience		X	X	X	X	X
County Trends			X		X	X
County × Year FE				X		

NOTE: All columns control for $\text{County}_{1990} \times$Sector and Year FE. Linear combination of coefficients using a 4% annual discount rate and summing over exponentiated coefficients.

What is Driving Observed Changes in Earnings?

How do earnings losses differ conditional on staying/leaving?

$$\Delta W = \sum_{i \in N_p} \left[\underbrace{D'_{ip} \times (w'_{ip} - w_{ip})}_{\text{Wage Cost for Stayers}} + \underbrace{D'_{io} \times (w_{io} - w_{ip})}_{\text{Wage Cost for Leavers}} \right]$$

What is Driving Observed Changes in Earnings?

How do earnings losses differ conditional on staying/leaving?

$$\Delta W = \sum_{i \in N_p} \left[\underbrace{D'_{ip} \times (w'_{ip} - w_{ip})}_{\text{Wage Cost for Stayers}} + \underbrace{D'_{io} \times (w_{io} - w_{ip})}_{\text{Wage Cost for Leavers}} \right]$$

Addressing Self-Selection into Job Separation

- Follow the same group of stayers/leavers before/after
- "Within group" earnings changes before/after (i.e. group FE)

Wage Comparisons:

- Compare stayer/leavers in polluting sector to all other workers

Earnings Estimates: Job Stayers versus Job Leavers

	Stayer (1)	Separator (2)
9-Year PDV	0.008	-1.375***
	(0.083)	(0.063)
N	6847	6847
$\text{Polluter}_{1990} \times \text{Year}$	X	X
$\text{Nonattain}_{1990} \times \text{Year}$	X	X
Cohort FE	X	X
Experience	X	X

- No change in earnings for those who remain at their firm
- Workers who separate experience large earnings losses

Sector Earnings Changes

Mechanisms: Regulation, Job Transitions, and Earnings Losses

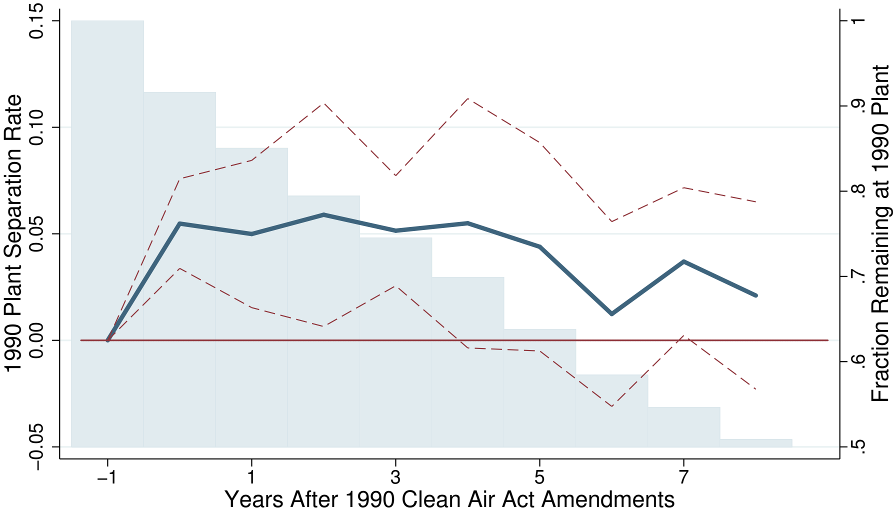
- What fraction of workforce is reallocated to other sectors?
- How long does this transition take?
- How do job flow dynamics compare to earnings estimates?

Relative likelihood of separation from pre-regulation employer

- A worker contributes a single observation for every year they remain with their pre-regulation firm
- Cohort averages yield separation rates
- The "risk set" evolves over time.

$$S_{1990,st} = \sum_{k=0}^{10} \eta_1^k [P_s \times N_c \times 1(\tau_t = k)] + \rho_{cs} + n_{ct} + p_{st} + \gamma_t + \epsilon_{cst}$$

New Regulations Increases the Rate of Job Separations



NOTE: Year 1 is first year of regulations. Bars plot Kaplan-Meier survivor probability for regulated sector.

Where Do Workers Relocate and How Do Relocation Costs Vary?

Use earnings records to track workers across locations-industries

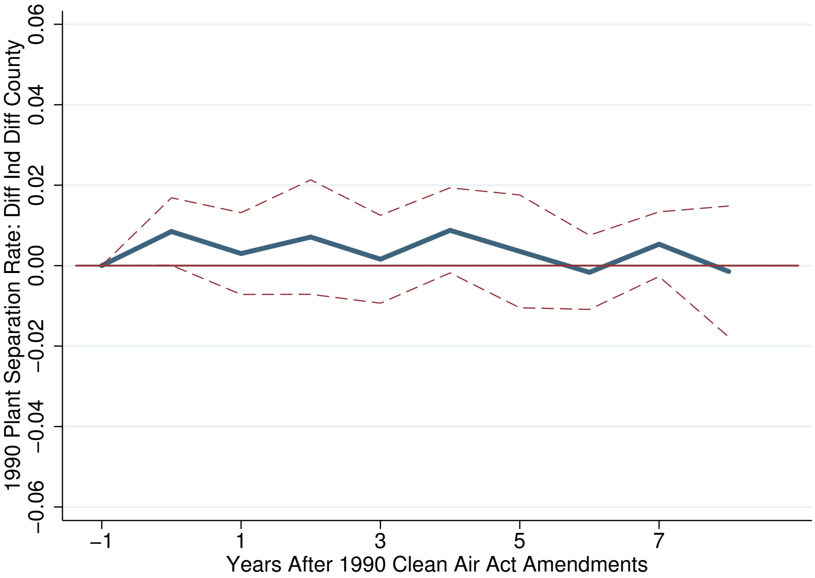
Polluting sectors (P_s)/switching counties (N_c)/after CAAA ($\tau_t \geq 0$)

$$S_{1990,s_j t} = \sum_{k=0}^{10} \eta_1^k [P_s \times N_c \times 1(\tau_t = k)] + \rho_{cs} + n_{ct} + p_{st} + \gamma_t + \epsilon_{cst}$$

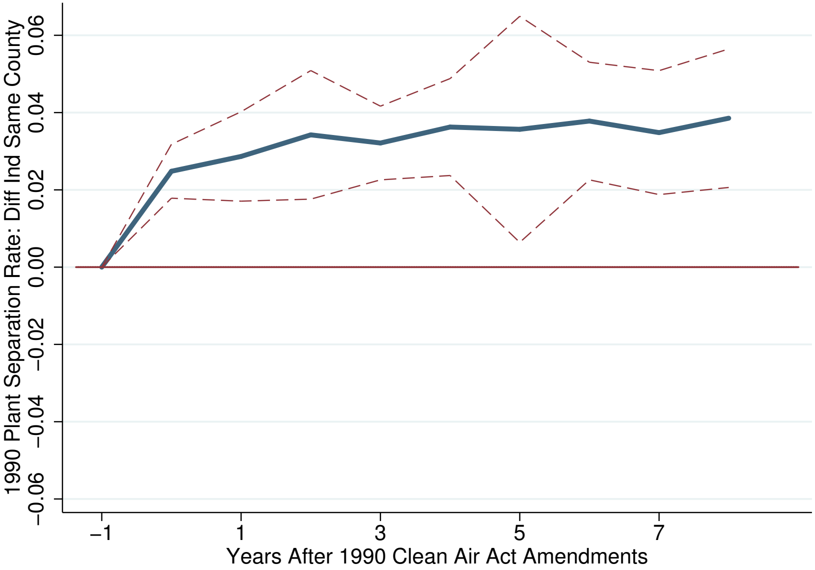
Prob. of switching from <u>location-industry s</u> to <u>location-industry j</u>

- Same County - Same 4 Digit SIC Industry
- Same County - Different 4 Digit SIC Industry
- Different County - Same 4 Digit SIC Industry
- Different County - Different 4 Digit SIC Industry

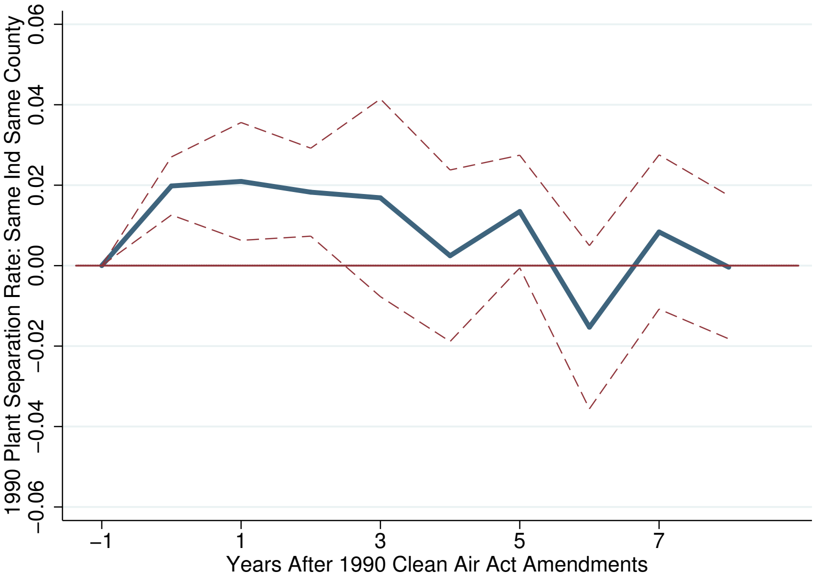
Transition Rate: Different Industry - Different County



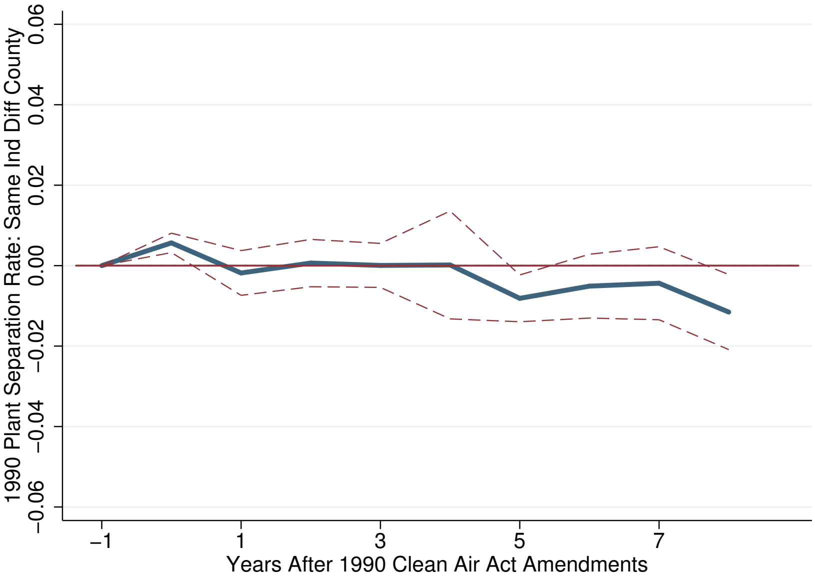
Transition Rate: Different Industry - Same County



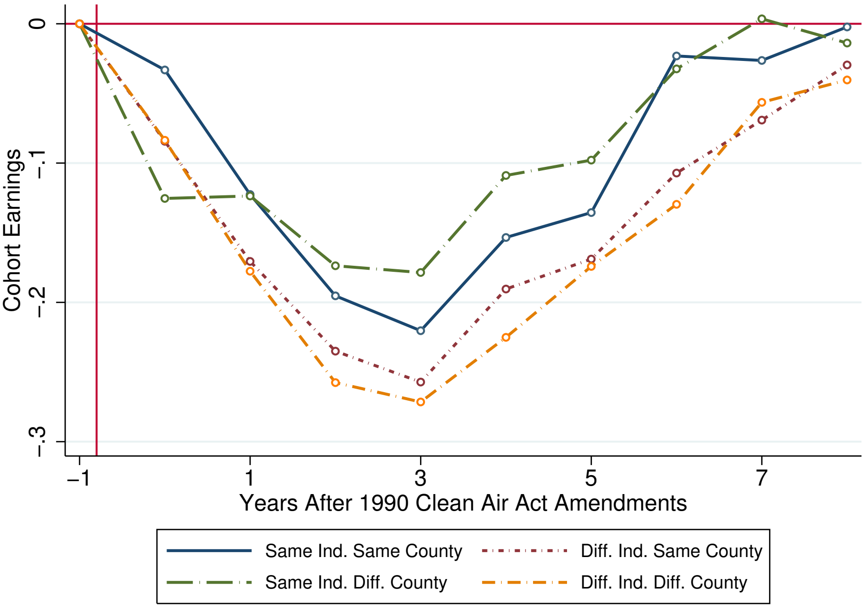
Transition Rate: Same Industry - Same County



Transition Rate: Same Industry - Different County



The Cost of Job Transitions: By Destination Location-Industry



Interpretation and Discussion

Are Losses to These Workers Social Costs?

- If workers paid their marginal product, wage losses are social costs
- If there are firm+worker rents (i.e. nash bargaining) then wage loss will overstate the social costs of reallocation.

Unemployment Insurance/Transfers

- Unemployment Insurance is a transfer (i.e. not a cost)
- Average UI payments: 20 weeks at 50% replacement
- Total increase in UI payments $\approx$ 1.2 billion
  - Social cost of public funds $\approx$ 40% (Gruber 2010)

Economic Costs of Policy Induced Labor Reallocation

- $9 billion in foregone earnings
- $480 million in DWL from social assistance

Costs Versus Benefits and Policy Implications

Estimated Benefits of Regulations

- EPA estimated health benefits of 1990 CAAA from 1990-2000 between 160 billion and 1.6 trillion dollar (1990$)

Total Costs of Regulations

- Short/Medium Run Transitional Costs (i.e. capital and labor)
- Plant Productivity losses (Greenstone, List, and Syverson 2011)

Policy Considerations

- 1990 Clean Air Employment Transition Assistance $\approx$ $50 million
- Foregone wage estimates presented here $\approx$ $9 billion

Conclusions

1. The average worker in a newly regulated plant experiences a PDV earnings loss equivalent to 23% of their pre-regulatory earnings
2. The costs of reallocating the workforce following the Clean Air Act Amendments of 1990 amounts to $9 billion in foregone earnings
3. Earnings changes driven by costly job transitions rather than a reduction in the industry wage
4. Reallocative costs are small relative to estimated benefits of CAA