Size-Based Environmental Regulation: Evidence from Major Clean Air Act Thresholds

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Size-Based Environmental Regulation is Common

Region	Policy	Running variable	Cutoff	Regulations
Canada	Canada Wide Standards	Emissions	10	Standards
China	CEMS	Emissions		Monitoring
EU	Industrial Emissions Directive	Thermal output		Many
EU	Emission Trading System	Emissions	25k	Allowances
EU	Seveso Directives I-II-III	Quantity	Many	Disaster prev.
S Africa	Air Quality Act	Capacity		Standards
US	Clean Air Act	Potential to emit	100	Many
US	Clean Water Act	CAFO size	2.5k	Many
US	Inflation Reduction Act	Methane emissions	25k	Fees
US	Safe Drinking Water Act	Customers	10k	Many
US-CA	AB32	Emissions	10k	Fees

Welfare Consequences of Size-Based Environmental Policy?

- **Motivation:**
  - Size-based environmental regulation common, understudied
  - "Major Source" regulation in US Clean Air Act important example
- **Approach:**
  - Analyze firm bunching around major source emissions thresholds
  - Model of size-based regulation and endogenous pollution abatement
  - Recover fixed, variable costs of regulation
  - Counterfactuals: replace size-based regulation with other instruments
- **Results:**
  - Bunching: many large firms shrink to avoid regulation
  - Enforcement: 0.5 standard deviations greater for major sources
  - Shadow price of pollution: ≈\$400/t NO_x; \$3,000/t PM; \$1,000/t VOCs?
  - Counterfactual policy instruments: impacts TBD

What is New Here?

- **Measuring costs of environmental regulation** (Hazilla and Kopp 1990; Carlson et al. 2000; Anderson and Sallee 2011; Fowlie et al. 2012; Deschenes et al. 2017; Fowlie et al. 2018; Allcott & Greenstone 2024; Shapiro and Walker 2024)
  - Size-based environmental regulation w endogenous abatement
  - Defensive investments for firms v. households

- **Bunching in response to size thresholds** (Saez 2010; Chetty et al. 2011; Kleven & Waseem 2013; Garicano et al. 2016; Kleven 2016; Chen et al. 2021; Bachas & Soto 2021; Askenazy et al. 2022; Akcigit et al. 2024)
  - Environmental application
    - Regulation $\neq$ ad valorem tax rate
    - Ex post data to validate bunching
    - Main outcome (economic costs) unobserved

- **Clean Air Act** (Becker and Henderson 2000; Greenstone 2002; Keller and Levinson 2002; List et al. 2004, 2005; Hanna 2010; Greenstone et al. 2012; Walker 2013; Lim 2016; Aldy et al. 2022)
  - First micro-level analysis of Potential to Emit (PTE).

Overview

- **Institutional Background**
- Data
- Bunching Evidence
- Theory
- Model-Based Estimates

Background: Clean Air Act Major Source Regulation

- **1970 Clean Air Act Amendments**
  - New and retrofitted stationary pollution sources require permits
  - Permits report Potential to Emit (PTE) pollution
- **PTE reflects permit details**
  - Factory design, technology
  - Pollution control equipment
  - Limits on hours of operation
- **Major Sources have PTE above statutory thresholds**
  - Default (Title V): PTE $\geq$ 100 tons/year
  - Alternative threshold (Extreme non-attainment): PTE $\geq$ 25 tons/year
  - Also: CA South Coast Air Quality District: PTE $\geq$ 10 tons/year

Background: Potential to Emit (PTE) Details

- **Engineering analysis by consultants, EPA**
  - Complex, unit-by-unit
  - Hard, not impossible to manipulate strategically; we test

- **Firm categories**
  - Major: PTE above threshold
  - Minor: PTE for standard design below threshold

- **Costs of major source regulation**
  - Tighter standards (LAER v. RACT/BACT)
  - Offset purchasing (major sources in non-attainment)
  - More frequent permit renewals
  - Enforcement, compliance actions

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Data: Example from PTE Microdata (1/2)

Entergy-Arkansas, Inc. Lynch Plant
Permit No.: 019-AOP-R2
CSN: 60-0087

Emissions from the facility include sulfur dioxide, nitrogen oxides, and particulates. A summary of facility wide emissions is provided in the following table. Specific emission unit information is located by the indicated cross reference pages.

EMISSION SUMMARY					
Source No.	Description	Pollutant	Emission Rates*		Cross Reference Page
			lb/hr	tpy	
	Total Allowable Emissions	PM_{10} PM SO_2 VOC CO NO_x	23.1 58.5 1305.5 16.6 626.4 1713.1	5.2 24.1 285.9 13.0 137.2 375.2	

Data: Example from PTE Microdata (2/2)

ExxonMobil 2019 Amendments to Baton Rouge Chemicals North

- *"Remove emission sources associated with processes that have been permanently removed from service or shutdown."*
- *"when previously operated for chemical production, was an emulsion styrene/butadiene rubber (SBR) manufacturing plant and emulsion acrylonitrile/butadiene rubber (NBR) plant ... the production processes and associated equipment were shut down."*

Pollutant	Before	After	Change
CO	53.97	0.27	-53.70
VOC *	277.14	8.60	-268.54

Pollutant	Before	After	Change
PM_{10}	21.87	3.22	-18.65
$PM_{2.5}$	16.64	3.22	-13.42
SO_2	6.65	0.02	-6.63
NO_X	262.98	1.25	-261.73

Data: PTE Microdata

Max relative PTE by facility	(1)
N (facility$\times$year)	426,968
N (facility)	46,348
Share by pollutant	
Carbon monoxide	0.10
Nitrogen oxides	0.23
Particulate matter	0.24
Sulfur dioxide	0.03
Volatile organic compounds	0.40
Share by state	
IL	0.49
KY	0.13
LA	0.19
MN	0.03
NC	0.05
NM	0.06
NV	0.09
WA	0.03
CA	0.02

Data: PTE Microdata

Max relative PTE by facility	(1)
Share by decade	
1990s	0.17
2000s	0.26
2010s	0.43
2020s	0.13
Share by PTE threshold	
10	0.02
25	0.15
100	0.82

Data: Other

- **Emissions: state inventories**

- **Compliance actions: EPA ICIS**
  - Eight types: compliance evaluations; stack tests; certifications; formal actions; informal actions; penalties; high priority violations; federally-reportable violations

- **Administrative Census microdata in Research Data Center**
  - Output, inputs: Census and Annual Survey of Manufactures (Census RDC)
  - Pollution Abatement Costs and Expenditures (PACE)
  - Probabilistic matching to PTE

- **Pollution Damages (AP3)**

Overview

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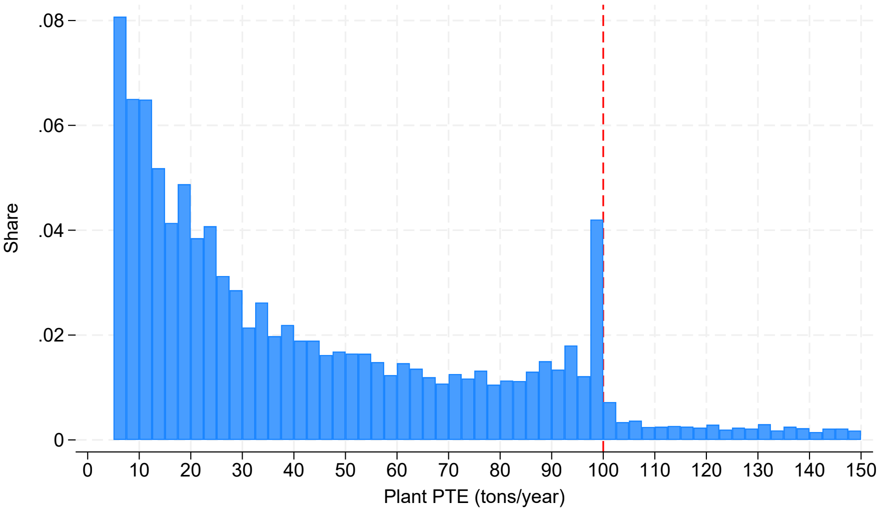
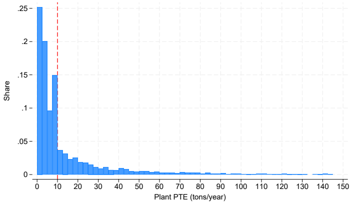
Bunching: PTE and Firm Density (1/2)

Figure: Threshold: 100 tons

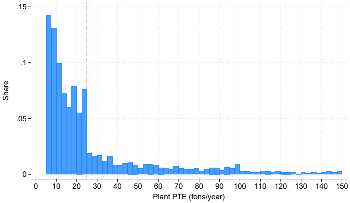


Bunching: PTE and Firm Density (2/2)

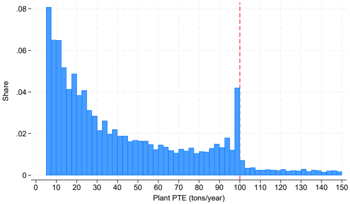
(a) Threshold: 10 tons



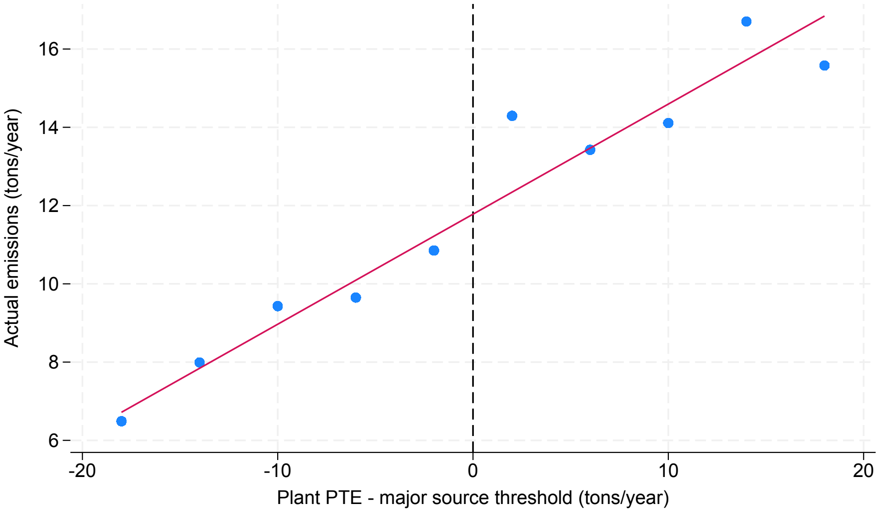
(b) Threshold: 25 tons



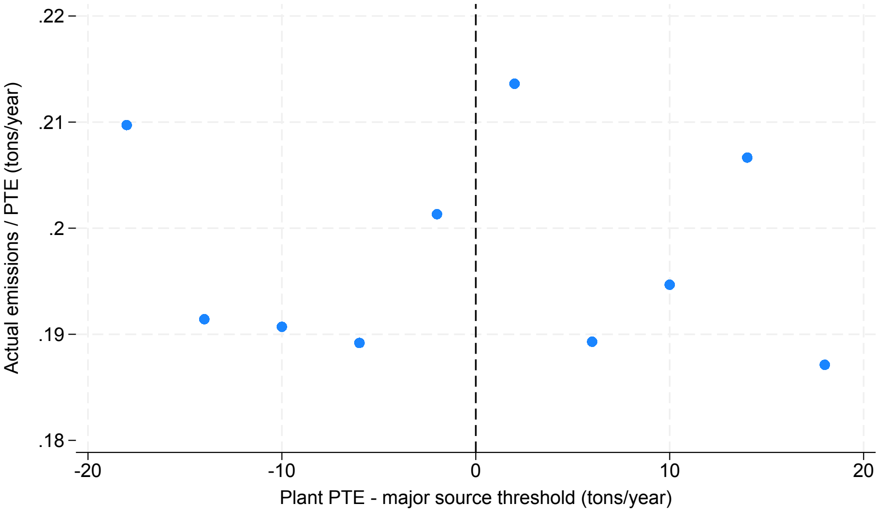
(c) Threshold: 100 tons



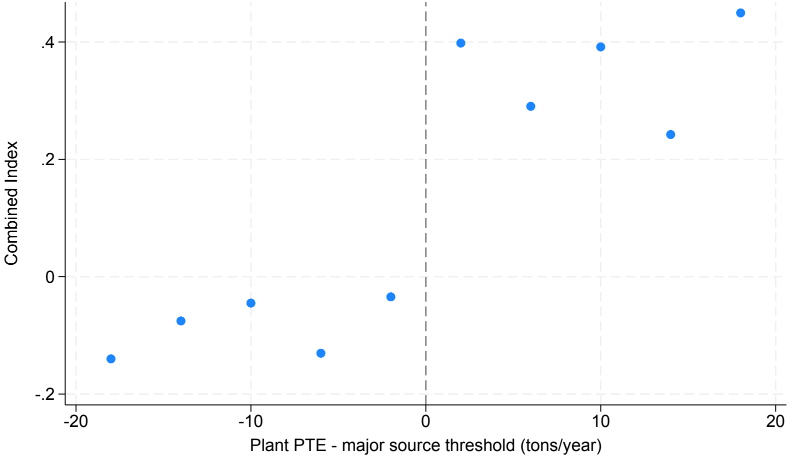
Bunching: PTE Versus Actual Emissions (1/2)



Bunching: PTE Versus Actual Emissions (2/2)



Bunching: Enforcement Actions



Combined index includes: compliance evaluations, certifications, informal/formal actions, formal actions with penalty, log penalty amount, high/low priority vio-

Separate actions

Overview

- Institutional Background
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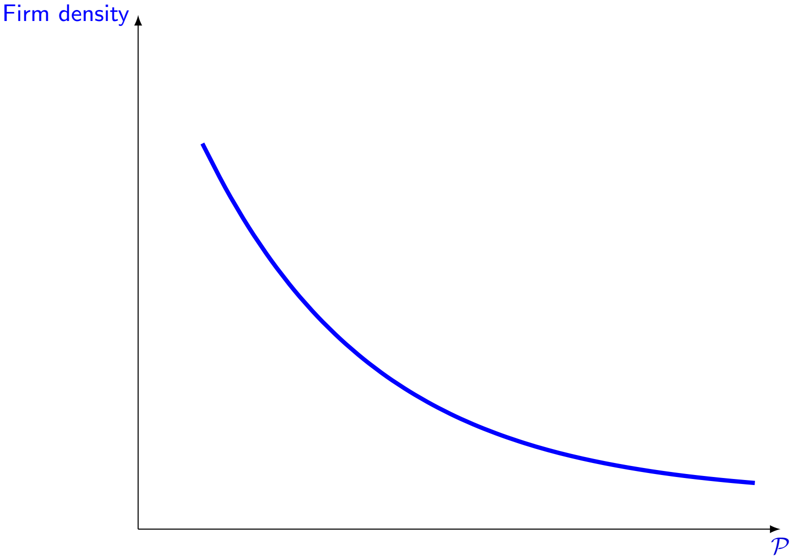
- **Theory**
- Model-Based Estimates

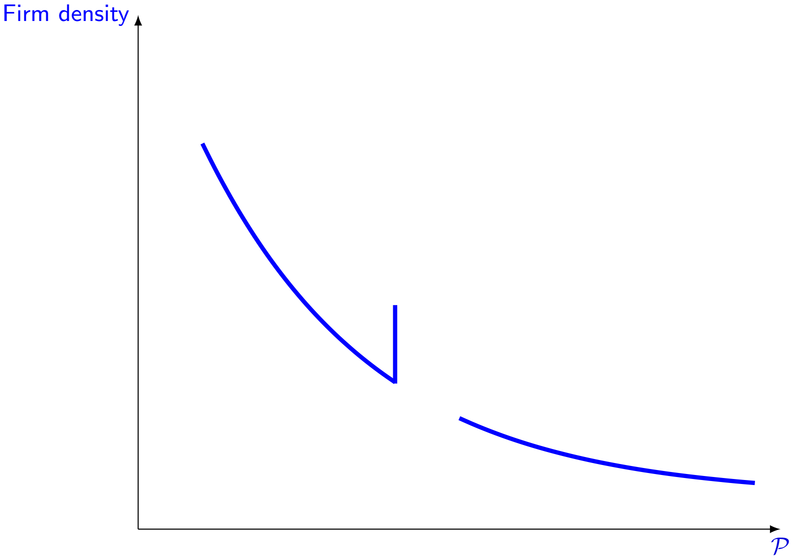
Model Overview

- **Model combines two elements**:
  - Heterogeneous firms (Lucas 1978, Melitz 2003, Garicano et al. 2016)
  - Endogenous abatement (Copeland & Taylor 2004, Shapiro & Walker 2018)
- **Assumptions**
  - Entrepreneurs choose entry, firm size
  - Minor firms pay emissions taxes
  - Major firms pay fixed cost, larger emissions tax
  - Firms choose share of potential output to use for abatement
- **Results**
  - Fixed, variable pollution taxes as functions of parameters, data
  - Maximum likelihood estimator of bunching behavior, parameters
  - Methodology: impact of counterfactual policies on welfare

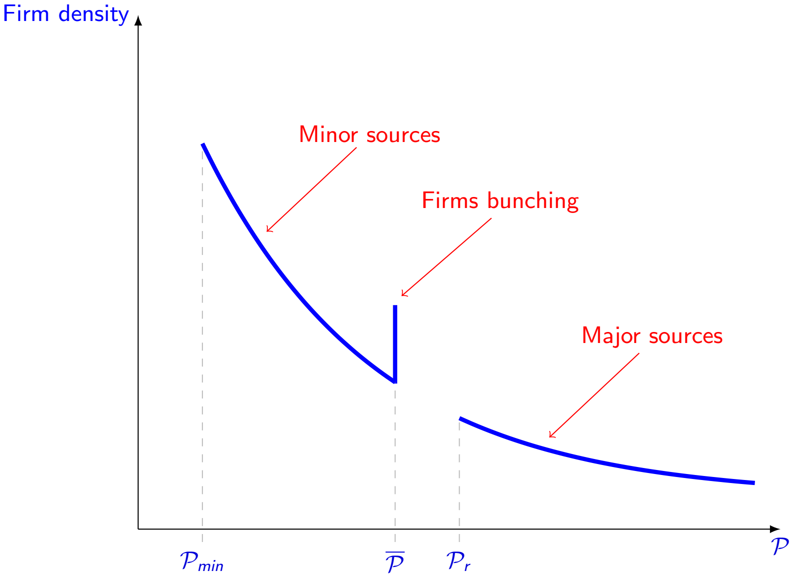
Model in Pictures: No Policy



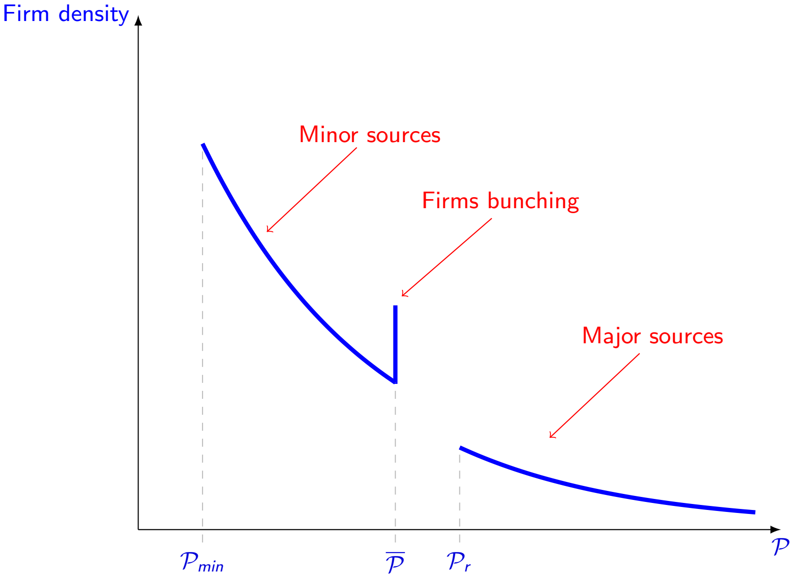
Model in Pictures: Add Size-Dependent Fixed Cost



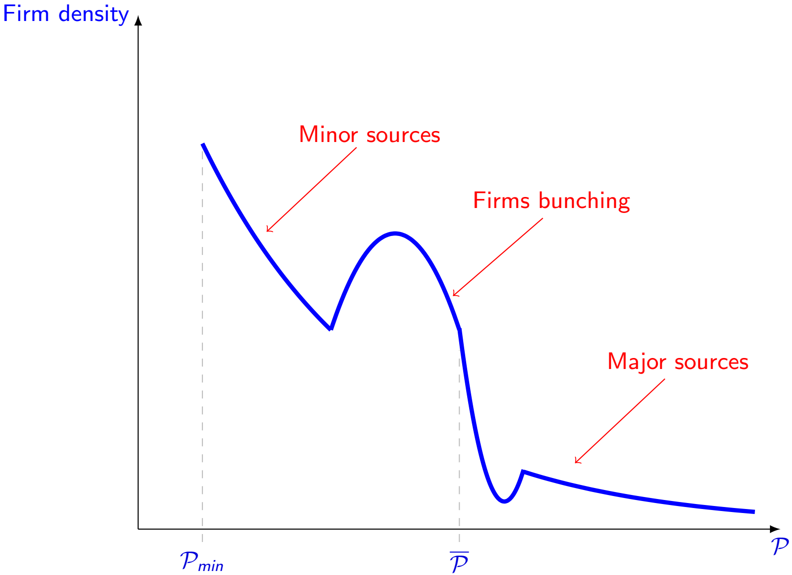
Model in Pictures: Add Size-Dependent Fixed Cost



Model in Pictures: Add Size-Dependent Variable Cost



Model in Pictures: Add Noise



Model Assumptions

Productivity distribution:

$$\phi(\alpha) = c_\alpha \alpha^{-\beta_\alpha}$$

Production (monopolistic competition):

$$\begin{aligned} q &= \kappa_q (1-a)\alpha n \\ \pi(\alpha) &= \max_{p,a} pq - wn - \tau\mathcal{P} - F \cdot 1[\mathcal{P} > \overline{\mathcal{P}}] \end{aligned}$$

Emissions:

$$\begin{aligned} e &= (1-a)^{1/\beta}\alpha n \\ \mathcal{P} &= \rho e \end{aligned}$$

Demand:

$$q = p^{-\sigma}$$

Notation:
c_α, β_α productivity distribution
α productivity; β pollution elasticity; κ_q baseline output; $\pi(\cdot)$ profit; ρ PTE/emissions
a share output for abatement; e emissions; n employment; p price; q output; w wage
$\tau \equiv \tau_0 1[\mathcal{P} \leq \overline{\mathcal{P}}] + \tau_1 1[\mathcal{P} > \overline{\mathcal{P}}]$ pollution tax; F fixed cost for major sources
$\mathcal{P}$ PTE; $\overline{\mathcal{P}}$ major source threshold

Plant Optimization

Abatement:

$$a^* = 1 - \left[\frac{1}{\tau\rho}\frac{\beta}{1-\beta}\left(\frac{w}{\alpha}\right)\right]^{\beta}$$

Pricing:

$$p^* = \frac{\sigma}{\sigma-1}\frac{\tau^{\beta}(w/\alpha)^{1-\beta}}{\beta^{\beta}(1-\beta)^{1-\beta}}\frac{\kappa_e^{\beta}\rho^{\beta}}{\kappa_q}$$

Employment, emissions:

$$\begin{aligned} n^* &= \left(\frac{\sigma}{\sigma-1}\frac{1}{\kappa_q}\right)^{-\sigma}\left(\frac{w}{\alpha(1-\beta)}\right)^{-\beta(1-\sigma)-\sigma}\left(\frac{\beta}{\tau\rho\kappa_e}\right)^{-\beta(1-\sigma)}\frac{1}{\alpha\kappa_q} \\ e^* &= \left(\frac{\sigma}{\sigma-1}\right)^{-\sigma}\left(\frac{w}{\alpha(1-\beta)}\right)^{(1-\beta)(1-\sigma)}\left(\frac{\beta}{\tau\rho\kappa_e}\right)^{1-\beta(1-\sigma)}\left(\frac{1}{\kappa_q}\right)^{1-\sigma} \\ \mathcal{P}^* &= \rho e^* \end{aligned}$$

Bunching firms

Notation:
c_α, β_α productivity distribution
α productivity; β pollution elasticity; κ_q baseline output; $\pi(\cdot)$ profit; ρ PTE/emissions
a share output for abatement; e emissions; n employment; p price; q output; w wage
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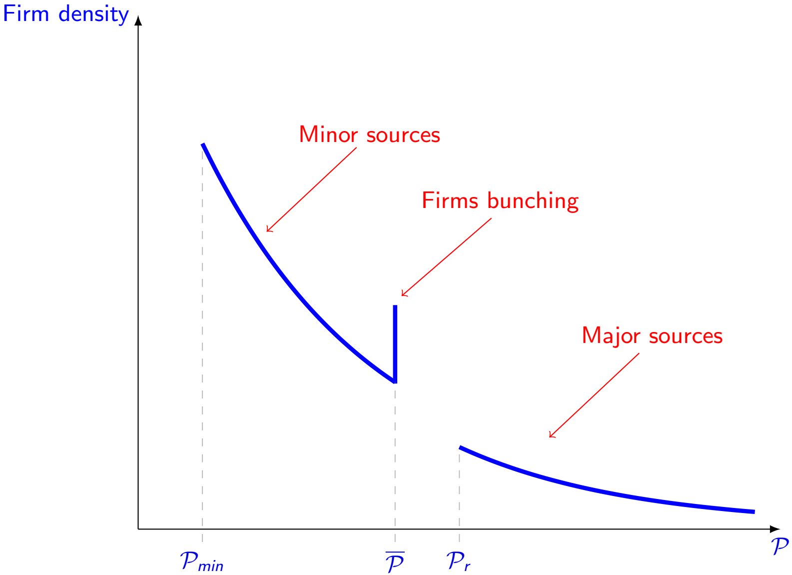
$\mathcal{P}$ PTE; $\overline{\mathcal{P}}$ major source threshold

Model Results: Distributions (1/2)

PTE conditional density:

$$\chi^*(\mathcal{P}) = \begin{cases} -\gamma \frac{\mathcal{P}^{\gamma-1}}{\left[\mathcal{P}_{min}^{\gamma} - T\mathcal{P}_{max}^{\gamma}\right]} & \text{if } \mathcal{P}_{min} \leq \mathcal{P} < \overline{\mathcal{P}} \\ \frac{\left[(\overline{\mathcal{P}})^{\gamma} - T(\mathcal{P}_r)^{\gamma}\right]}{\left[\mathcal{P}_{min}^{\gamma} - T\mathcal{P}_{max}^{\gamma}\right]} & \text{if } \mathcal{P} = \overline{\mathcal{P}} \\ 0 & \text{if } \overline{\mathcal{P}} < \mathcal{P} < \mathcal{P}_r \\ -\gamma \frac{T\mathcal{P}^{\gamma-1}}{\left[\mathcal{P}_{min}^{\gamma} - T\mathcal{P}_{max}^{\gamma}\right]} & \text{if } \mathcal{P}_r \leq \mathcal{P} \leq \mathcal{P}_{max} \end{cases}$$

Model Results: Distributions (1/2)



Model Results: Distributions (2/2)

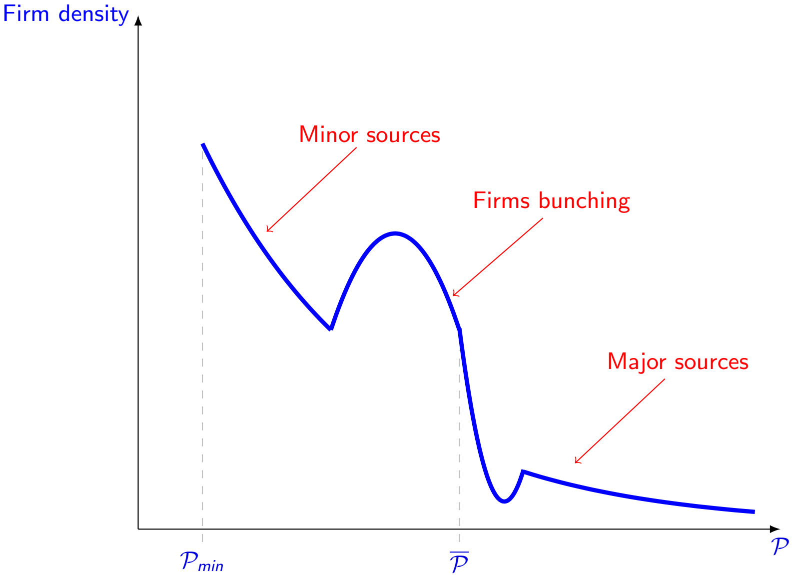
Empirical model:

$$\mathcal{P} = \mathcal{P}^*(\alpha)e^{\varepsilon}, \quad \varepsilon \sim \mathcal{N}(0, \sigma_\varepsilon^2)$$

Empirical model-PTE conditional density:

$$\mathbb{P}(x < \mathcal{P} \mid \varepsilon) = \begin{cases} 0 & \text{if } \ln\mathcal{P} - \ln\mathcal{P}_{min} < \varepsilon \\ \frac{\left[\mathcal{P}_{min}^{\gamma} - (\mathcal{P}e^{-\varepsilon})^{\gamma}\right]}{\left[\mathcal{P}_{min}^{\gamma} - T\mathcal{P}_{max}^{\gamma}\right]} & \text{if } \ln\mathcal{P} - \ln\overline{\mathcal{P}} < \varepsilon \leq \ln\mathcal{P} - \ln\mathcal{P}_{min} \\ \frac{\left[\mathcal{P}_{min}^{\gamma} - T(\mathcal{P}_r)^{\gamma}\right]}{\left[\mathcal{P}_{min}^{\gamma} - T\mathcal{P}_{max}^{\gamma}\right]} & \text{if } \ln\mathcal{P} - \ln\mathcal{P}_r < \varepsilon \leq \ln\mathcal{P} - \ln\overline{\mathcal{P}} \\ \frac{\left[\mathcal{P}_{min}^{\gamma} - T(\mathcal{P}e^{-\varepsilon})^{\gamma}\right]}{\left[\mathcal{P}_{min}^{\gamma} - T\mathcal{P}_{max}^{\gamma}\right]} & \text{if } \ln\mathcal{P} - \ln\mathcal{P}_{max} \leq \varepsilon \leq \ln\mathcal{P} - \ln\mathcal{P}_r \\ 1 & \text{if } \varepsilon < \ln\mathcal{P} - \ln\mathcal{P}_{max} \end{cases}$$

Model Results: Distributions (2/2)



Model Counterfactuals (1/2)

- **Five counterfactuals**
  - All sources minor ($\tau_1' = \tau_0$)
  - All sources major ($\overline{\mathcal{P}} = 0$)
  - All sources minor, emissions fixed ($\tau_1' = \tau_0$, $\mathbb{E}[\mathcal{P}] = \mathbb{E}[\mathcal{P}']$)
  - Optimal fixed cost ($F' = F^*$)
  - Optimal threshold ($\overline{\mathcal{P}}' = \overline{\mathcal{P}}^*$)

Model Counterfactuals (2/2)

- Baseline PTE, output: $\mathbb{E}[\mathcal{P}]$, $\mathbb{E}[q]$
- Counterfactual #1: all sources minor. PTE, output:

$$\mathbb{E}[q^{'}] = \frac{c_\alpha}{\kappa_q^{-\sigma}} \left(\frac{\sigma}{\sigma - 1} \left(\frac{w}{1-\beta} \right)^{1-\beta} \left(\frac{\tau_0 \rho \kappa_e}{\beta} \right)^{\beta} \right)^{-\sigma} \frac{\left[\alpha_{max}^{\sigma(1-\beta)-\beta_\alpha+1} - \alpha_{min}^{\sigma(1-\beta)-\beta_\alpha+1} \right]}{[\sigma(1-\beta) - \beta_\alpha + 1]}$$

$$\mathbb{E}[\mathcal{P}^{'}] = c_\alpha \rho \left(\frac{\sigma}{\sigma - 1} \right)^{-\sigma} \left(\frac{w}{(1-\beta)} \right)^{-\tilde{\beta}} \left(\frac{\beta}{\tau_0 \rho} \right)^{1-\beta(1-\sigma)} \frac{\left[\alpha_{max}^{\tilde{\beta}-\beta_\alpha+1} - \alpha_{min}^{\tilde{\beta}-\beta_\alpha+1} \right]}{\tilde{\beta} - \beta_\alpha + 1}$$

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- Theory
- **Model-Based Estimates**

Estimation

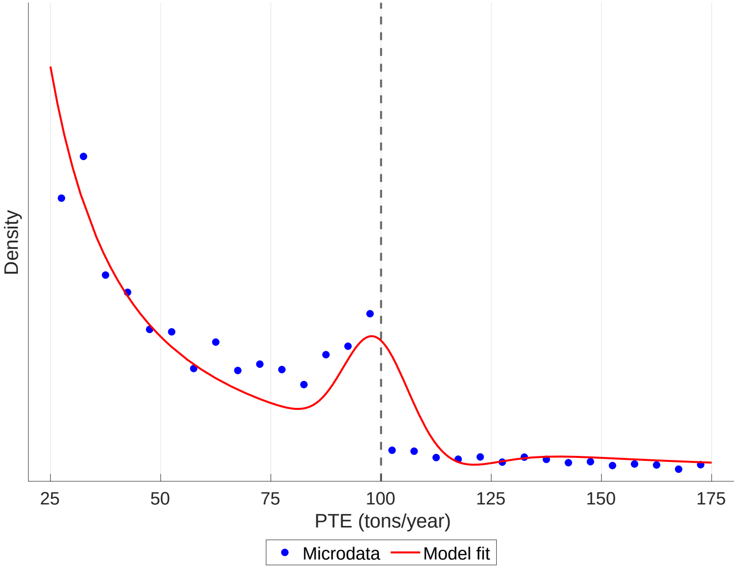
Maximum likelihood estimator:

$$\max \prod_i \chi(\mathcal{P}_i \mid \mathcal{P}_r, T, \gamma, \sigma_\epsilon)$$

	(1)
$\mathcal{P}_r$	123.625
	(1.565)
T	0.8674
	(0.007)
γ	-0.5172
	(0.012)
σ_ϵ	0.076
	(0.006)

Notation:
$\mathcal{P}_r$ smallest major source; T major/minor pollution taxes; γ ability dispersion; σ_ϵ PTE noise

Model Fit



Density
25
50
75
100
125
150
175
PTE (tons/year)
Microdata
Model fit

Counterfactual Policies

Forthcoming, once disclosed from Census Research Data Center

Preliminary calibrations:

$$\tau = \frac{1}{\rho} \frac{\beta}{1-\beta} \frac{wn}{e}$$

- Mean emissions from National Emissions Inventory.
- Mean employment (38), salary ($52,915) from Census of Manufacturers.

Pollutant	**Mean emissions (tons/year)**	τ **($/ton)**
PM	8	2961
VOC	13	1822
NO_x	65	364

Conclusions

- **Size-based environmental regulation common, understudied**
- **Clean Air Act Major Source Regulation**
  - Causes substantial bunching
  - Meaningful economic costs, environmental benefits?
- **Forthcoming**
  - Counterfactual results

Plant Optimization: Bunching Firms

$$\bar{q} = \frac{\kappa_q \bar{e}}{\kappa_e} \left[\frac{\alpha}{w} \frac{(\sigma - 1)}{\sigma} \left(\frac{\kappa_q \bar{e}}{\kappa_e} \right)^{-1/\sigma} (1-\beta)\kappa_q \right]^{\frac{\sigma(\beta-1)}{\beta-\beta\sigma-1}}$$

$$\bar{p} = \left(\frac{\kappa_q \bar{e}}{\kappa_e} \left[\frac{\alpha}{w} \frac{(\sigma - 1)}{\sigma} \left(\frac{\kappa_q \bar{e}}{\kappa_e} \right)^{-1/\sigma} (1-\beta)\kappa_q \right]^{\frac{\sigma(\beta-1)}{\beta-\beta\sigma-1}} \right)^{-1/\sigma}$$

$$\bar{n} = \frac{\bar{e}}{\alpha \kappa_e} \left[\frac{\alpha}{w} \frac{(\sigma - 1)}{\sigma} \left(\frac{\kappa_q \bar{e}}{\kappa_e} \right)^{-1/\sigma} (1-\beta)\kappa_q \right]^{-\frac{\sigma}{\beta-\beta\sigma-1}}$$

$$e = \frac{\overline{\mathcal{P}}}{\rho}$$

Notation:
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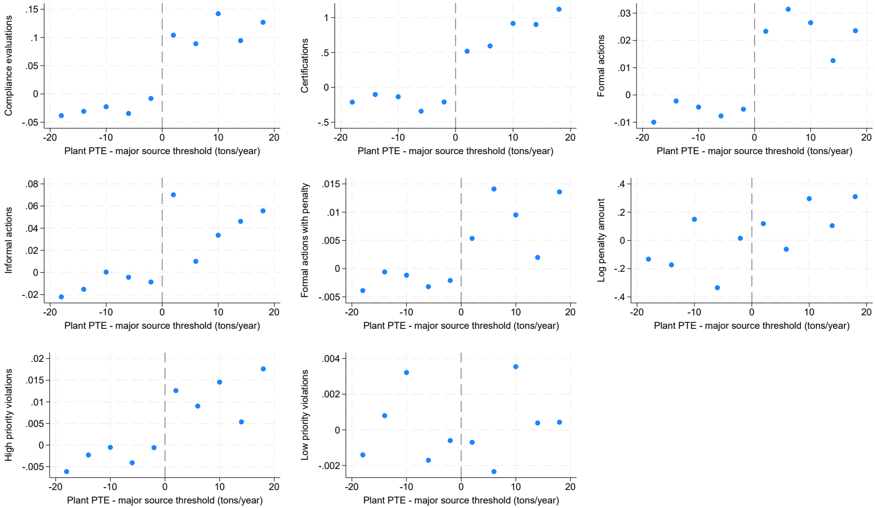
Bunching: Enforcement Actions



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