Dynamic Regulation with Firm Linkages: Evidence from Texas

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[1] All views are those of the authors and not the Commission, its Commissioners, or the United States Government.

Background

Environmental regulation covers an enormous amount of industrial activity in the U.S.

- E.g. over 60,000 plants are subject to federal hazardous waste regulation
- 80% of U.S. population lives within 3 miles of a regulated facility.

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- Who is violating law & by how much
- How costly it is for firms to comply

Perform inspections to uncover violations

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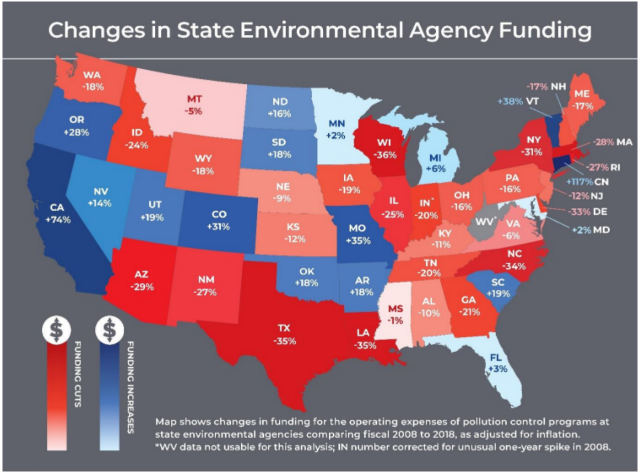

Costly Enforcement

Workaround: target enforcement and inspections toward

- Especially egregious violations
- Repeat violators (dynamics/escalation)
- Plants with behavior likely correlated with past offenders (dynamic linking)
  - Example: correlation through management practices at commonly-owned plants

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This paper: how effective is a **linked escalation** anti-pollution enforcement regime?

Contributions

First empirical study of the efficiency of a dynamic, linked enforcement regime

- Blundell, Gowrisankaran, and Langer (2020) study dynamics

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Novel, estimable framework with dynamic moral hazard, accommodating many firms with large portfolios of interdependent plants

New panel data set with compliance scores, as well as annual plant-level inspections, violations, ownership networks

Related Lit

Preview of counterfactual findings

- Simulate budget increase: 10% $\uparrow$ average probability of inspecting each plant
  - Objective: minimize total social cost of violations
- **Unlinked escalations**: outperform random inspections in multiplant firms 54.7%
- **Linked escalations**: outperform random inspections in multiplant firms by 80.0%
  - Why? Decompositions: combination of a 'correlated targeting mechanism' and a 'firm-wide moral hazard mechanism'

Plan

1. Context and data Jump
2. Descriptive analysis Jump
3. Model Jump
4. Estimation and identification Jump
5. Findings Jump
6. Conclusion Jump

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Context and data

- Texas Commission on Environmental Quality (TCEQ) enforcement of Clean Water Act and Resource Conservation and Recovery Act
  - Covers around 10000 plants, only $\sim 31.4\%$ inspected each year
- Panel (2012-2020): ownership networks, inspections, violations, penalties, scores
  - Many large portfolios
- Fix ideas: common 'firm' is an owner of several gas stations, each with an underground petroleum storage tank

Context and data: two-score regime

- Regulator uses 'compliance scores' to target inspections and penalties on prior compliance histories
  - Can also target based on observed plant/firm characteristics
- **Plant-level score**
  - Index increasing in past violations, $0 =$ clean record, older violations discounted
- **Firm-wide score** aggregates co-owned plants' scores
  - TCEQ calls firm-wide scores 'person scores'; associated with an individual human
  - Firm scores weight plant scores by the 'complexity' of each plant

Why use scores?

Plant-level escalations valuable for two reasons:

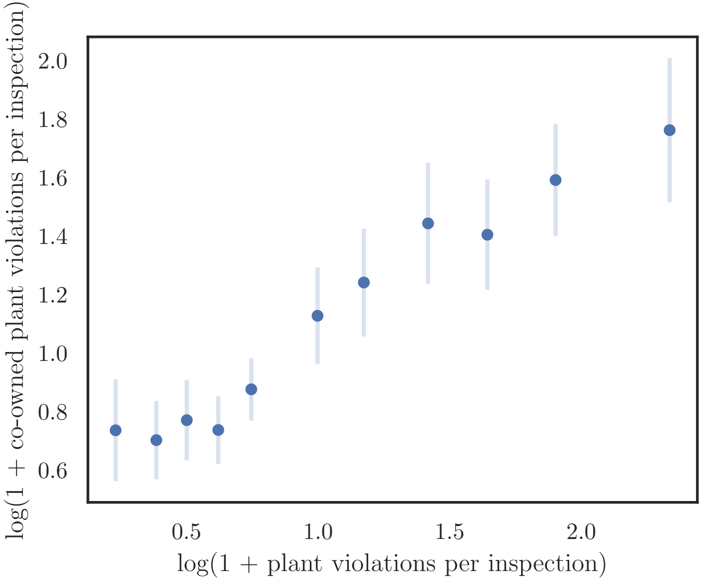
1. Past violations informative about which plants have high cost of compliance $\rightarrow$ better targeting of inspections
2. Threat of escalation tomorrow can deter plants from violating today

Using firm-wide scores (linking):

1. Can improve targeting by leveraging information about co-owned plants with correlated types (**"correlated targeting"** effect)
2. Can amplify deterrence by spreading threat of escalation across entire portfolio (**"firm-wide moral hazard"** effect)

Plan

Violations are correlated across commonly-managed plants

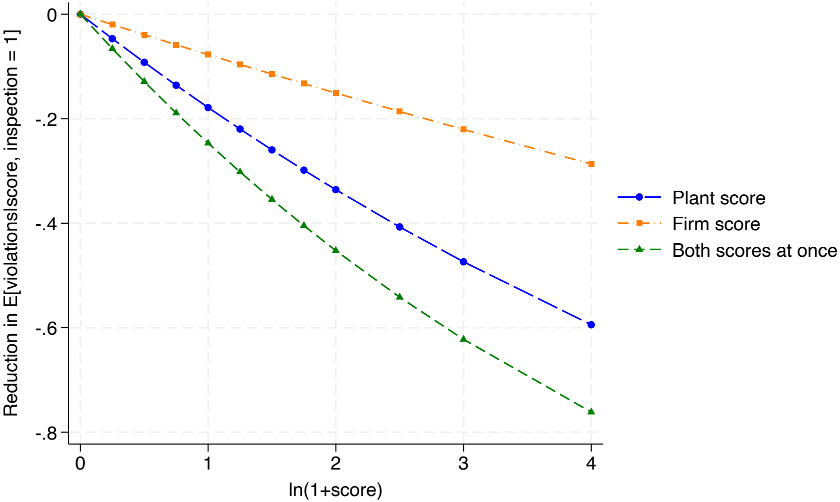


The regulator targets inspections (as well as penalties) based on linkages

	(1)	(2)	(3)
Dependent Variable	Inspection	Inspection	Inspection
Log(1+firm score)	0.062	0.062	0.054
	(0.018)	(0.018)	(0.018)
Log(1+plant score)	0.121	0.121	0.122
	(0.017)	(0.017)	(0.017)
Env. justice score	-	-0.060	-
	(-)	(0.053)	(-)
Year FEs	Yes	Yes	Yes
NAICS Category FEs	Yes	Yes	Yes
Region FEs	No	No	Yes
N	54621	54621	54621

Evidence of moral hazard and deterrence

Regress violations on $\hat{z}_{jt}$ with plant fixed effects



Robustness: production reallocation

Plan

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Model setup: dynamic, discrete-time game

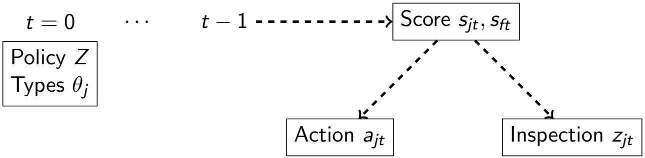
- **Agents:**
  - Regulator, and a set of firms f who each own a portfolio of plants $j \in \mathcal{J}_f$
- **Types:**
  - Plants differ in (private info) types θ_j that index benefit of polluting actions: $\theta_j b(a_j)$
  - Types may be correlated between co-owned plants
- **States:** Vector of scores $\mathbf{s}$, comprises $[s_{jt}]_{j \in \mathcal{J}_f}$ and s_{ft}
- **Actions:**
  - Regulator commits to inspection policy, mapping s_f and s_j to prob. of inspection
  - Firms choose negligent actions at each plant $a_j \rightarrow$ violations drawn from Poisson(a_j)

Model: period t process

$t = 0$ $\cdots$ $t-1 \dashrightarrow$ $\boxed{\text{Score } s_{jt}, s_{ft}}$

Policy Z
Types θ_j

Model: period t process



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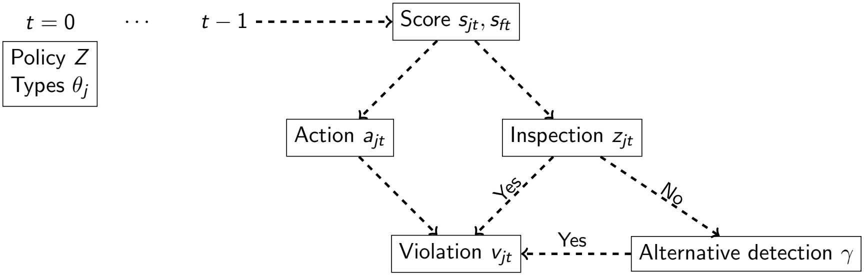

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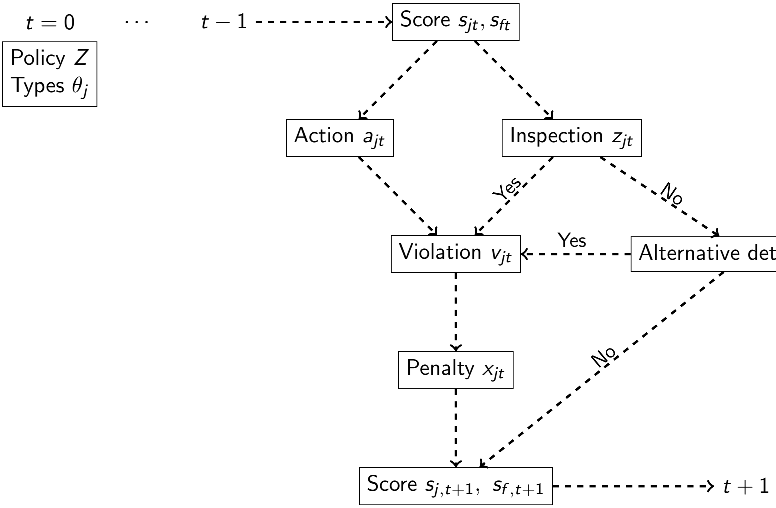

Model: firm's problem

- Firm's problem: choose action for each plant to max. discounted sum of payoffs
- Flow payoff in each period:

$$\pi_j(a_j; s_j, s_f) = \underbrace{\theta_j b(a_j)}_{\substack{\text{Flow benefit}\\ \text{from negligent}\\ \text{actions}}} - \Big(\underbrace{\bar{z}_{g(j)}(s_j, s_f)}_{\text{Inspection}} + \underbrace{\gamma(1 - \bar{z}_{g(j)}(s_j, s_f))}_{\substack{\text{Alternative methods}\\ \text{to detect violations}}}\Big) \times \underbrace{\mathbb{E}_{v_j}(v_j x(s_j, s_f) | s_j, s_f, a_j)}_{\substack{\text{Expected penalty}\\ (= a_j x(s_j, s_f))}}$$

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- Overall problem (bold denotes vectors):

$$V(\mathbf{s}) = \max_{\{a_j\}_{j\in\mathcal{J}}} \sum_{j\in\mathcal{J}} \pi_j(a_j; s_j, s_f) + \beta \mathbb{E}_{\mathbf{z},\mathbf{v}} \left[V(\mathbf{s}') \middle| \, \mathbf{s}, \mathbf{a} \right]$$

Model: firm's problem

- Actions that solve previous problem are equivalent to actions that solve n_{plant} equations (one per plant):

$$\max_{a_j} \underbrace{\pi_j(a_j; s_j, s_f)}_{\text{Plant flow payoff}} + \beta \mathbb{E}_{\mathbf{z},\mathbf{v}} \left[\underbrace{V_j(\mathbf{s}')}_{\substack{\text{Plant} \\ \text{continuation} \\ \text{value}}} + \underbrace{\sum_{k \in \mathcal{J}/j} V_k(\mathbf{s}')}_{\substack{\text{Other plants'} \\ \text{continuation values}}} \,\middle|\, \mathbf{s}, \mathbf{a}^*_{-j}, a_j \right]$$

- **Computational challenge**: curse of dimensionality in $\sum_{k \in \mathcal{J}/j} V_k(\mathbf{s}')$

Model: firm's problem - solution algorithm

- **Solution**: 'continuation value sufficiency' (in spirit of Gowrisankaran and Rysman (2012))
  - (i) choose action at each plant using three states: $s_j, s_f, W_j = \sum_{k \in \mathcal{J}/j} V_k(\mathbf{s})$
  - (ii) AR(1) transition beliefs over reduced state consistent with overall firm-level behavior
  - Intuition: firm uses a heuristic to account for the cross-plant effects of a_j
- **Algorithm** (computed separately for each firm portfolio in data):
  - (Outer loop): Solve for AR(1) transition parameters for each plant j that are consistent with firm-level and regulator behavior (via forward simulation)
  - (Inner loop): Solve for optimal actions and value functions for each plant j given transition parameters.

Model: regulator's problem

$$\min_{Z\in\mathcal{Z}} V^R = \min_{Z\in\mathcal{Z}} \underbrace{\int\int \sum_{f\in\mathcal{F}} \sum_{j\in\mathcal{J}_f} h_{g(j)} a_j \, dF(a,s;Z,\theta)\, dG_\theta(\theta)}_{\text{Total social cost of violations}}$$

subject to: [Total inspections] $\leq$ [Inspection budget]

- G_θ: dist. of plant types
- $F(a, s; Z, \theta)$: stationary dist. of plant actions and scores
- Z: inspection policy (mapping from scores $\rightarrow$ inspection probability)
- $h_{g(j)}$: social cost of violation for plant j in industry $g(j)$

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Estimation and identification: outline

1. Estimate offline parameters (regulator's inspection CCP, alternative detection γ)
2. Estimate parameters of firm's problem via simulated method of moments
3. Estimate industry-specific 'perceived' social costs from regulator's problem
   - Identification: leverage assumption that regulator is choosing the inspection function optimally to minimize social costs

Jump to findings

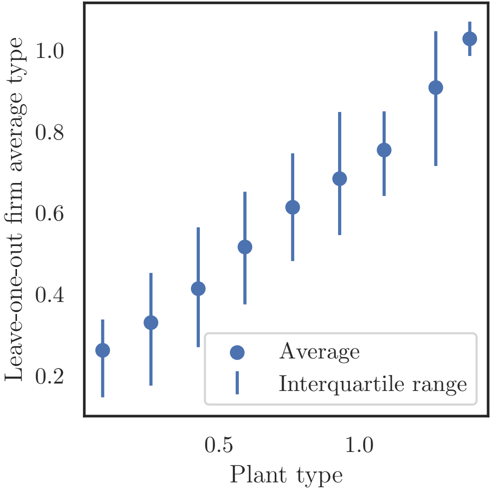
Estimation and identification: correlation of types within-firm

Plant type parameterization:

$$\theta_j = \Big| \underbrace{\bar{\theta}_{g(j)}}_{\text{Industry mean}} + \underbrace{\varepsilon_j}_{\substack{\text{Plant type}\\ \sim N(0,\sigma_F^2)}} + \underbrace{\varepsilon_{f(j)}}_{\substack{\text{Firm type}\\ \sim N(0,\sigma_J^2)}} \Big|$$

Identify within-firm θ_j correlation:

Match moments: within firm vs between firm variance of observed violations



Other parameterizations | Moments | Detail: parameters

Plan

Findings: outline

- **Simulate budget increase**: 10% $\uparrow$ average probability of inspecting each plant
- **Aim**: allocate budget to minimize total (perceived) social cost of violations
- Consider four types of regulation this increase could be spent on:
    1. Random inspections
    2. Unlinked inspections
    3. Linked inspections
    4. (50/50 mix)
- **Implementation**: change coefficients in inspector policy function:

$$Pr(inspect) = Logit(\beta_{0g(j)} + \beta_1 \ln(1 + s_{jt}) + \beta_2 \ln(1 + s_{ft}))$$

Findings: summary of counterfactuals

	$\uparrow$ Inspections budget by 10%. Spent on:	
	Unlinked	Linked
%Δ Social cost vs random: Portfolios ≥ 2	-54.7%	-80.0%
%Δ Social cost vs random: Total	-42.6%	-50.9%
Decomposition: Total		
$=$ Correlated targeting mechanism	-12.7%	-10.9%
$+$ Firm-wide moral hazard mechanism	-42.0%	-69.1%

Conclusion

Findings: summary of counterfactuals - decomposition

- Linked regulation works through two mechanisms:
- 1. Correlated targeting mechanism
  - Links provide useful information about where next to investigate.
  - Scores target enforcement towards plants most responsive to regulation
  - Compute: fix map of scores to actions ($a_j^*(\hat{\mathbf{s}}_j)$) and distribution of scores; increase regulation
- 2. Firm-wide moral hazard mechanism
  - Links allow regulator to punish common owner for bad behavior.
  - Scoring deters firm from choosing high actions through the threat of firm-wide escalation
  - Compute: allow mapping of scores to actions to change: $a_j^*(\hat{\mathbf{s}}_j)$

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Conclusion Detail: targeting

Conclusion

- **Central question for regulators**: how to efficiently target scarce enforcement resources?
- **This paper**: new empirical framework to study dynamic linked regulation, a common form of targeting
  - Framework can accommodate firms with large portfolios of plants
  - Apply it to a novel dataset from Texas in context of hazardous wastes regulation and Clean Water Act regulation
- **Main finding**: linked regulation can add significant value due to correlation of types within firms

Thank You!

Related literature

- Empirical models of regulation
  - e.g. Blundell et al. (2020), Kang and Silveira (2021), Abito (2020), Duflo et al. (2018), Timmins (2022), Sileo (2022), Alé-Chilet et al (2022), Chen et al (2021)
- Role of management on firm outcomes
  - e.g. Bloom et al. (2019), Goldfarb and Xiao (2011), Diardili et al (Forthcoming)
- Descriptive literature on environmental regulation
  - e.g. Gibson (2019), Colmer et al. (2022), many others...
- Theory literature on deterrence mechanisms; mechanism design when types are correlated
  - e.g. Mookherjee and Png (1994), Polinsky and Shavell (1998), Crémer and Mclean (1988), Varas et al. (2020)

Back

Other parameterizations

- Flow benefit $b(a_j) = a_j^y$
- Plant-specific transition matrices $R_{0,j}$, $R_{1,j}$ in law of motion for scores:

$$R_{0,j} = \begin{bmatrix} 0 \\ 0 \\ r_w^{0,j} \end{bmatrix}, \quad R_{1,j} = \begin{bmatrix} r_{s_j}^{s_j,g(j)} & 0 & 0 & r_v^{s_j,g(j)} \\ 0 & r_{s_f}^{s_f,j} & 0 & r_v^{s_f,j} \\ 0 & 0 & r_w^{w,j} & r_v^{w,j} \end{bmatrix} \tag{1}$$

- Inspection policy function:

$$z_{jt} = \frac{\exp\left\{\beta_{0g(j)}^z + \beta_1^z \ln(1 + s_{jt}) + \beta_2^z \ln(1 + s_{ft})\right\}}{1 + \exp\left\{\beta_{0g(j)}^z + \beta_1^z \ln(1 + s_{jt}) + \beta_2^z \ln(1 + s_{ft})\right\}} \tag{2}$$

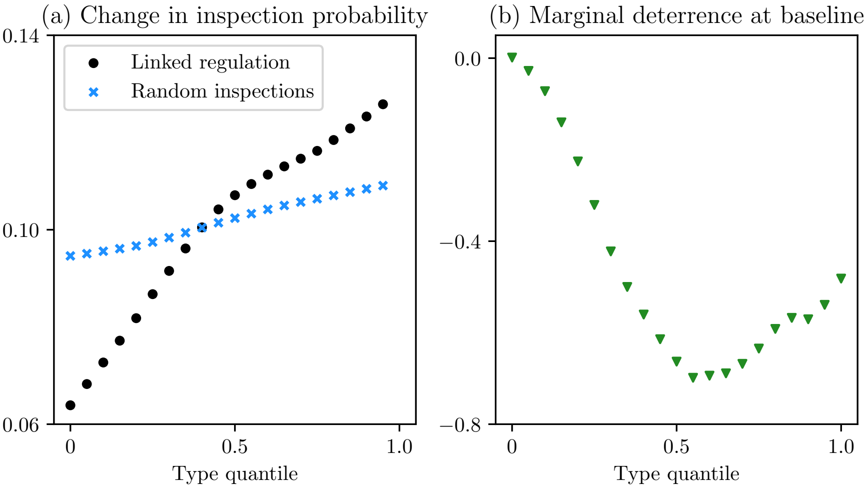
Return: firm parameterization

Robustness: production reallocation

	(1) 1[Exit]	(2) 1[Exit]	(3) 1[Exit]
Log(1+firm score)	0.005	0.003	0.002
	(0.002)	(0.002)	(0.002)
Log(1+plant score)	-0.01	-0.009	-0.009
	(0.002)	(0.002)	(0.002)
Year FEs	Yes	Yes	Yes
NAICS Category FEs	No	Yes	Yes
Region FEs	No	No	Yes
Only multi-plant firms	Yes	Yes	Yes
N	18331	18331	18331

Return: deterrence

Detail: targeting



Return: counterfactuals

Detail: estimated parameters

Parameter	Estimate	Std. Error	Parameter	Estimate	Std. Error
Mean type $\bar{\theta}_g$			*Perceived social cost* h_g		
Manufacturing	0.466	0.116	Manufacturing	0.965	-
Resources	0.011	0.076	Resources	1.077	0.057
Services	0.181	0.122	Services	1.005	0.057
Trade	0.026	0.04	Trade	1.191	0.052
Transportation	0.413	0.097	Transportation	1.391	0.034
Utility	0.473	0.148	Utility	1.0	0.081
Type variances					
Plant-level, σ_J^2	0.189	0.052			
Firm-level, σ_F^2	0.256	0.059			
Shape parameter, y	0.612	0.128			

Return: estimation

Detail: moments

Moment	Simulated	Empirical
Mean violations		
Manufacturing	0.226	0.194
Resources	0.103	0.075
Services	0.136	0.135
Trade	0.111	0.090
Transportation	0.121	0.146
Utility	0.220	0.187
Viol. variance share		
Within-firm	0.194	0.217
Within-to-across-firm ratio	0.632	0.626
Responsiveness	-6.455	-6.489

Return: estimation