Policy Devolution and Cooperation Dilemmas

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Abstract

How do public good spillovers influence agent effort in an interconnected environment? We develop a model for a general class of problems in which agents share the provision of a public good and downstream agents experience spillovers. We characterize endogenous agent effort as the result of their location in the network, their responsibility over the resource, and a regulated facility's location within the jurisdiction. We examine our findings with an empirical exercise centered on the regulation of 6,000 major water pollution sources under the U.S. Clean Water Act. We construct a novel dataset of U.S. state water pollution regional offices and use geographic information on agency jurisdictions, watershed boundaries, and elevation-induced streamflow to characterize the propensity for agents to exert detection effort in their local environment. Our empirical results support our expectations.

Decisionmakers of all stripes face a common challenge: the effects of their decisions rarely stay where they start. The consequences of a given decision often spill over into other domains, affecting other actors, and creating new challenges for policymakers. Changes to a first-grade curriculum ripple through the entire educational pipeline; zoning laws shape not just property values but also how communities develop over time; tax policies might encourage some actors to move across state lines, altering the very problems those policies were designed to address.

No arena is immune to spillovers, but environmental policy is particularly vulnerable. The natural flow of water, air, and wildlife need not align with the administrative boundaries that humans have created, and the consequences of pollution or habitat destruction often extend far beyond the borders of the jurisdiction where the pollution originated. Unlike social or economic policies, where spillovers can sometimes be mitigated through adjustments, environmental spillovers are dictated by physical realities that are much harder to control. This makes environmental policy uniquely challenging, as policymakers must navigate a complex web of interconnected consequences that extend beyond their direct influence.

Institutions charged with managing environmental pollution generally do so by subdividing environmental resources into administrative jurisdictions. These jurisdictions are then charged with overseeing both the resources and any potential spillovers (Gray and Shadbegian 2004). Upstream governments and private firms can take actions that reduce environmental pollution loads for downstream entities. However, governments with jurisdiction over pollution sources have strong incentive to promote spillover to downwind and downstream jurisdictions when possible (Monogan, Konisky and Woods 2017). Incentives for spillover are more challenging still, when administrative jurisdictions further fragment environmental resources which introduces perverse incentives for regulators and facilities alike (Lipscomb and Mobarak 2016).

The degree of this fragmentation is critical to understanding how and when spillovers materialize. Fragmented jurisdictions create a complex network of interactions, where each jurisdiction has its own priorities and constraints. When administrative boundaries dissect natural systems, such as watersheds, this misalignment can undermine collective efforts to manage environmental quality. Regulators may focus their efforts narrowly within their jurisdiction, neglecting the broader implications of upstream or downstream pollution. At the same time, firms might exploit jurisdictional divides to reduce regulatory scrutiny or compliance costs.

In this paper, we examine how the fragmentation of environmental resources by administrative boundaries affects the incentives of regulatory agents to enforce environmental regulations. Using a formal model, we explore how jurisdictional design and fragmentation influence regulatory effort and facility compliance, focusing on the special case where "gravity goes one way"—that is, where the flow of spillovers follows a partial order. Though indeed special, the case includes important examples such as our motivating case, water pollution (where water flows only downstream), but also policies where consequences of decisions occur latter in time (where time flows only forward), or where decisions are made at different levels of government (where power flows only downward). By highlighting the interplay between fragmented institutions and spillover effects in this structured setting, our analysis contributes to a deeper understanding of the challenges posed by environmental governance in fragmented policy spaces.

Our approach draws from, and contributes to, a diverse set of established theoretical frameworks, particularly in the domain of network games and spillover effects.[1] The foundational work of Bergstrom, Blume and Varian (1986) inspired a rich tradition in studying effort-exertion games, particularly in contexts where public goods and spillovers are crit-

[1] To deliver public goods efficiently, bureaucratic agents must coordinate their efforts. This type of coordination can be enhanced by information sharing and other factors that reduce transaction costs (Gailmard and Patty 2013*a*,*b*). Yet, ample literature also suggests that agents have incentive to free ride on other agents' efforts when performance accountability mechanisms are weak or fragmented (Carrigan 2017; Monogan, Konisky and Woods 2017; Ting 2003; Whitford 2002). In this paper, we argue that the imposition of administrative boundaries on a policy domain create incentives that, under some conditions, undermine public good delivery. In other words, governance gaps between political and environmental boundaries induce coordination challenges across agents (Ekstrom and Young 2009), but the degree to which this matters for policy delivery depends on the nature of the fragmentation and spillovers that result.

ical. This line of research was significantly advanced by Ballester, Calvó-Armengol and Zenou (2006), who demonstrated that effort-exertion games with finite populations can be decomposed into two key components: a network-game component with local payoff complementarity effects and a global component with payoff substitution effects. These insights highlighted the dual nature of agents' incentives in networked environments. Bloch and Zenginobuz (2007) extended these ideas by modeling spillover effects that could be either symmetric or asymmetric. Their findings underscored the unique challenges posed by asymmetric spillovers, particularly in achieving equilibrium uniqueness and determining the sign of substitution effects. Similarly, Bramoullé and Kranton (2007) examined the interplay between substitution effects and specialization outcomes, identifying conditions under which some agents exert effort while others strategically free ride.

Closer to our focus, Ogawa and Wildasin (2009) developed a model that captures interactions between agents and firms, though their emphasis was on productivity and jurisdictional transfers rather than regulatory detection. Other notable contributions include Bramoullé, Kranton and D'Amours (2014), who showed that the lowest eigenvalue of a network serves as a sufficient statistic for understanding how other agents' behavior influences a given agent's choices. This result points to the importance of well-partitioned networks in achieving optimal regulatory outcomes. Allouch (2015) further advanced this tradition by providing a general existence result for network games of good provision, focusing on resource distribution among consumers rather than regulatory effort. Building on these foundations, Elliott and Golub (2019) explored how the spectral properties of networks influence welfare outcomes, integrating insights from both Bramoullé and Allouch. Finally, Galeotti, Golub and Goyal (2020) studied the effects of policy interventions on welfare in large networks, demonstrating that simple interventions often yield the best outcomes.

While many of these theoretical advances are motivated by environmental concerns, they remain abstract and detached from the specific challenges of regulatory enforcement. Few provide actionable insights without imposing significant additional structure, and those that do often leave empirical validation as an open task. Moreover, none of the existing literature models the strategic interaction between regulators and facilities in a fragmented resource context. We address these gaps by developing a formal framework to study water regulation in a fragmented policy space. Our model combines insights from network games with a well-specified structure of spillovers. Facilities are embedded within a network, where ties—representing spillover intensity—are determined by physical properties such as proximity and flow size. Facilities choose compliance levels with local regulations, while regulatory agents decide how much effort to allocate toward detecting noncompliance within their jurisdiction.

Our theoretical contribution is twofold. First, and more generally, we provide conditions under which the regulatory game admits a pure-strategy Nash equilibrium. These conditions are largely independent of the network's specific structure, allowing us to study and compare networks with varying degrees of spectral tidiness. Second, and more specifically, two parametric vignettes illustrate simple mechanisms for how regulatory effort is influenced by jurisdictional design. Our results show that regulators exert less effort at facilities near the "bottom" of their jurisdiction, whereas upstream regulators allocate more effort when their authority over their jurisdiction is greater.

We evaluate insights from our model in the context of government agents tasked with providing public goods in the form of watershed protection. The imposition of administrative boundaries on a policy domain imposes a network structure that shapes agents' incentives to exert effort in delivering the public good. Specifically, we consider the artificially-created administrative boundaries that shape the quality of an agent's jurisdiction by dissecting watersheds. These dissections place limits on agents' responsibility for managing resources under their discretion and impose downstream relationships. In such settings, under certain conditions, spillover may incentivize agents to use their discretion to select effort levels that undermine the provision of the good. In other words, governance gaps between political and environmental boundaries induce coordination challenges across agents (Ekstrom and Young 2009), but the degree to which this matters for policy delivery depends on the nature of the fragmentation and spillovers that result.

We examine our expectations using a newly-constructed dataset of U.S. state regional offices charged with water pollution control responsibilities. These regional administrative offices are created by state environmental agencies and are used to regulate activities under the U.S. Clean Water Act, such as permitting and compliance assurance. Using GIS software, we generate a novel dataset that spatially delineates each regional office's administrative jurisdiction and its overlap with watershed boundaries. We further use elevation and stream flow data to demarcate whether the portion of a watershed within a given administrative jurisdiction is upstream or downstream from adjacent regional offices. We then use linear random-effects GLS regression analysis to investigate the degree to which higher levels of environmental resource (*i.e.,* watersheds) boundary fragmentation by administrative boundaries results in less regulatory effort from regional agents. The subjects of the analysis are the roughly 6,000 major water pollution facilities for which we have detailed historical data on compliance and regulatory activity under the Clean Water Act.

We introduce the model and our analysis of the problem in Section 1. In Section 2, we consider the specific case of spillovers in water pollution enforcement in the U.S. In Section 3, we introduce our empirical strategy and we present our results. We then conclude.

1 A Theory of Regulation with Ordered Spillover

In this section, we develop a formal model of environmental regulation with ordered spillovers. In our model we consider two questions in turn. First, we examine how a single regulator expends effort across multiple facilities within an administrative jurisdiction. Second, we investigate how the extent of watershed dissection by administrative jurisdictions shapes two neighboring agents' regulatory efforts.

We draw upon a broad literature on agent motivations in regulatory enforcement to guide our setup. Agents pursue enforcement decisions to maximize net political support by securing lower pollution for the least cost (Stigler 1971; Peltzman 1976). Enforcement decisions reflect a combination of detection effort and punishment selection (Becker 1968; Ehrlich 1973). While punishment selection may range from maximal to either flexible or pragmatic enforcement (Gunningham 2011; Scholz 1991; Hunter and Waterman 1996), detecting noncompliance is foundational to any of these tactics. With respect to detection effort, regulators typically pursue a dual-group auditing framework. Regulators divide facilities into at least two detection target groups based upon past compliance records. One groups consists of higher priority facilities with more troublesome compliance records and the other group contains lower priority facilities with more cooperative histories (Friesen 2003; Harrington 1988). Regulators adjust their detection efforts across these facility groups to gain returns in the form of specific and general deterrence against noncompliance (Gray and Shimshack 2011). With these lessons in mind, we now introduce our model.

We take as primitive the *domain,* which is a pair $(V, \gtrsim)$ with V a set and $\gtrsim$ a relation on V. Elements of V are *locations,* and for locations $v, w \in W$, infixed $v \gtrsim w$ reads "v is upstream of w;" we assume $\gtrsim$ is reflexive, transitive, and antisymmetric.

The strategic-form game played in the domain includes two classes of players.

1. The first class of players is a finite, but not empty, set of *regulators,* $R = \{1, \ldots, n_R\}$. Each regulator $r \in R$ is associated with a *jurisdiction,* J_r. These jurisdictions partition V—*i.e.,* each J_r is a nonempty subset of V where $r \neq s \Rightarrow J_r \cap J_s = \varnothing$ and $\bigcup_{r \in R} J_r = V$. Call the jurisdiction partition $\mathcal{J} = \{J_r\}_{r \in R}$.

2. The second class of players is a finite, but not empty, set of *facilities,* $F = \{1, \ldots, n_F\}$. Each facility is assigned a location $v_f \in V$ and thus a regulator $\rho : F \to R$. Thus, for each regulator, the set of regulatory responsibilities is simply the inverse map $\rho^{-1} : R \rightrightarrows F$ gathering for Regulator r all facilities $f \in F$ such that $\rho(f) = r$ (or put differently, all facilities such that $v_f \in J_r$). Naturally, we assume $|\rho^{-1}(r)| \geqslant 1$ for all $r \in R$—*i.e.,* each regulator is responsible for at least one regulatory candidate.

Nothing precludes $|R| = 1$ or $|F| = 1$.[2]

The two classes have distinct available strategies.

1. Each regulator decides how hard to inspect compliance at each of her regulatory candidate facilities. Formally, this is an effort vector

$$e_r = (e_f)_{f \in \rho^{-1}(r)} \in E_r := [0,1]^{|\rho^{-1}|}. \tag{1}$$

   We gather these into an overall effort vector $e = (e_r)_{r \in R}$, where $e = (e_r, e_{-r})$ serves as the usual game-theoretic abuse of notation. As an additional abuse of notation, we can also write $e = (e_f)_{f \in F}$, where e_f is the effort level Regulator $\rho(f)$ expends at Facility f; we again have the notation $e = (e_f, e_{-f})$.

2. Each facility decides how much to comply with regulations. Formally, Facility $f \in F$ chooses $c_f \in [0,1]$ We gather these into $c = (c_f)_{f \in F}$ and again remember the intuitive notational convention $c = (c_f, c_{-f})$.

A strategy profile is a pair tuple $a = (e, c) \in A := [0,1]^{2|F|}$. When useful, we restrict a to a subset of facilities $G \subseteq F$ via $a|_G = (e|_G, c|_G) := (e_f, c_f)_{f \in G} \in [0,1]^{2|G|}$, so that a is just shorthand for $a|_F$. In case $G = \varnothing$, $a|_G$ is left undefined.

The regulators' and facilities' respective decisions influence the relevant political-geographic outcomes via two mechanisms. Politically, they determine each facility's probability of detection. Formally, we introduce the *probability of detection*, $p_f : A \to [0,1]$. We make three straightforward assumptions about this probability.

Assumption 1 (Probability of Detection)

The probability of detection $p_f : A \to [0,1]$ is continuous and satisfies

1. Effort Monotonicity: $e'_f \leqslant e''_f \Rightarrow p_f\left(\left(e'_f, e_{-f}\right), c\right) \leqslant p_f\left(\left(e''_f, e_{-f}\right), c\right)$*; and*

[2] In the context of the Georgia map in Figure 4, V is the set of lines making up each of the rivers, R is the set of regional offices with $|R| = 7$, and F is the set of dots along the rivers, each representing a facility. A watershed like the highlighted Flint River watershed is a subset of V that satisfies certain properties, which we study in a companion paper.

2. Compliance Monotonicity: $c'_f \leqslant c''_f \Rightarrow p_f\left(e, \left(c''_f, c_{-f}\right)\right) \leqslant p_f\left(e, \left(c'_f, c_{-f}\right)\right)$.

In words, the continuity assumption asserts that small changes in effort or compliance map to small changes in the probability of detection; Effort Monotonicity asserts that more regulatory effort yields higher chances of detection; and Compliance Monotonicity asserts that more compliance yields lower chances of detection.

Geologically, noncompliance harms water quality. Define $\mathsf{UF}_{\gtrsim}(v) := \{f \in F \mid v_f \gtrsim v\}$ which is the set of facilities upstream of location $v \in V$.[3] For all locations $v \in V$, we introduce the *water quality* $q_v : A \to [0,1]$. We make some assumptions about q_v.

Assumption 2 (Water Quality)

For all locations $v \in V$, water quality $q_v : A \to [0,1]$ takes the form

$$q_v(a) = \begin{cases} 1, & \mathsf{UF}_{\gtrsim}(v) = \varnothing \\ \widetilde{q}_v\left(a|_{\mathsf{UF}_{\gtrsim}(v)}\right), & \mathsf{UF}_{\gtrsim}(v) \neq \varnothing \end{cases}, \tag{2}$$

where $\widetilde{q}_v : [0,1]^{|\mathsf{UF}_{\gtrsim}(v)|} \to [0,1]$ is continuous and satisfies

1. Compliance Monotonicity: *we have*

$$c'|_{\mathsf{UF}_{\gtrsim}(v)} \leqslant c''|_{\mathsf{UF}_{\gtrsim}(v)} \Rightarrow \widetilde{q}_v\left(e|_{\mathsf{UF}_{\gtrsim}(v)}, c'|_{\mathsf{UF}_{\gtrsim}(v)}\right) \leqslant \widetilde{q}_v\left(e|_{\mathsf{UF}_{\gtrsim}(v)}, c''|_{\mathsf{UF}_{\gtrsim}(v)}\right);$$

2. Convexity in Local Effort: *for all $x \in [0,1]$, the set*

$$\left\{e_r \in [0,1]^{|\rho^{-1}(r)|} \;\middle|\; q_v\left(\left(e_r, e_{-r}\right), c\right) \geqslant x\right\} \tag{3}$$

is convex; and

3. Fluidity in the Stream: *the map $(a, v) \mapsto \widetilde{q}_v(a) : A \times V \to [0,1]$ is continuous in v.*

[3] Of course, we can have $\mathsf{UF}_{\gtrsim}(v) = \varnothing$ for locations not downstream of any facilities—*e.g.*, the source of a river. Such locations being outside a regulator's control, they will be cast aside as uninteresting.

In words, the functional form assumption asserts that the water quality at a given location depends only on behavior upstream; the continuity assumption asserts that small changes in regulatory effort and compliance yield small changes in quality; Convexity in Local Effort asserts that the quality at location v does not suffer should the regulator in question diversify her efforts across various effort divvyings equally desirable; Compliance Monotonicity asserts that water quality is better when facilities comply more; and Fluidity in the Stream precludes discontinuous jumps as time/gravity/procedural order flows.

The two classes of player have different kinds of preferences over these consequences. For each regulator $r \in R$, we have a utility function $u_r : A \to \mathbb{R}$. Naturally, we make some assumptions about the regulators' preferences.

Assumption 3 (Regulator Preferences)

For all regulators $r \in R$, the utility function $u_r : A \to \mathbb{R}$ takes the form

$$u_r(a) = \widetilde{u}_r \left((q_v(a))_{v \in J_r}, -e_r \right), \tag{4}$$

and where $\widetilde{u}_r : [0,1]^{J_r} \times [-1,0]^{\left|\rho^{-1}(r)\right|}$ is continuous and satisfies

1. Quality Monotonicity: $q' \leqslant q'' \Rightarrow \widetilde{u}_r(q', -e_r) \leqslant \widetilde{u}_r(q'', -e_r)$; *and*

2. Effort Monotonicity: $-e'_r \leqslant -e''_r \Rightarrow \widetilde{u}_r(q_r, (-e'_r, e_{-r})) \leqslant \widetilde{u}_r(q_r, (-e''_r, e_{-r}))$.

In words, the functional form assumption asserts that a regulator's utility depends only on the quality across locations in her jurisdiction and on how much effort she has exerted; the continuity assumption asserts that small changes in quality and effort yield small changes in regulator utility; Quality Monotonicity asserts that a regulator does better when her locations feature higher quality; and Effort Monotonicity asserts that effort is costly.

As for the facilities, we introduce $u_f : A \to \mathbb{R}$ as follows.

Assumption 4 (Facility Preferences)

For all facilities $f \in F$*, the utility function* $u_f : A \to \mathbb{R}$ *takes the form*

$$u_f(a) = \widetilde{u}_f\left(c_f, -p_f(a)\right) \tag{5}$$

where $\widetilde{u}_r : [0,1] \times [-1,0] \to \mathbb{R}$ *is continuous and satisfies*

1. Compliance Monotonicity: $c' \leqslant c'' \Rightarrow \widetilde{u}_f\left(c', p\right) \leqslant \widetilde{u}_f\left(c'', p\right)$*; and*

2. Fear of Detection: $-p' \leqslant -p'' \Rightarrow \widetilde{u}_f\left(c, -p'\right) \leqslant \widetilde{u}_f\left(c, -p''\right)$.

In words, the functional form assumption asserts that a facilty's utility depends only on how much it complies and on the probability it is detected if non-compliant; the continuity assumption asserts that small changes in compliance or probability of detection yield small changes in utility; Compliance Monotonicity asserts that compliance is costly; and Fear of Detection asserts that facilities do worse when they expect to be detected.

This is a strategic-form game, and we are interested in its pure-strategy Nash equilibria. We can say the following.

Proposition 5 (Equilibrium Existence)

Any regulatory game in the domain has at least one pure-strategy Nash equilibrium.

The result is a straightforward application of the Debreu-Glicksberg-Fan theorem; we provide a proof in the appendix for completeness, but the required continuity and quasiconcavity assumptions are all satisfied by our setup.

1.1 Vignettes

To provide some simple actionable mechanisms, we introduce two vignettes. In both we have $V = [0, 1]$, which we envision as a set of locations within a watershed.

1.1.1 Regulators Work Less Downstream

We first consider how a single regulator expends effort across multiple facilities. Suppose—for now—that there is a single regulator, $R = \{1\}$ and two facilities, $F = \{A, B\}$, where $v_A = 0$ and $v_B \in (0, 1]$. In other words, Facility A is upstream at the top of the domain (at $v_A = 0$), and v_B tells us how far downstream Facility B is. Put differently, $1 - v_B$ tells us how far upstream from the jurisdictional boundary Facility B is.

The regulator inspects the two facilities by choosing a pair of effort levels $e = (e_A, e_B) \in [0, 1]^2$, and each facility $f \in F$ must choose a compliance level $c_f \in [0, 1]$; we gather these into $c = (c_A, c_B)$, and we gather all choices into $a = (e_A, e_B, c_A, c_B) \in A := [0, 1]^4$. These choices influence the probability that the regulator detects each facility engaging in noncompliance: Facility f is detected with probability $p_f(e, c) = e_f\,(1 - c_f)$.

For both facilities $f \in F$, we define the instantaneous environmental effect $\phi_f : A \times \Theta \to [0, 1]$

$$\phi_f(a; \theta) = c_f + (1 - c_f)p_f(a)\mu,$$

where $\mu \in (0, 1]$ captures the regulator's ability to mitigate the consequences of noncompliance in case of detection. As $\mu \downarrow 0$, detection offers less and less of an environmental benefit; in case $\mu = 1$, detection allows for perfect mitigation. To encode how noncompliance influences downstream water quality, we introduce evolution functions,

$$((a; \theta); v) \xmapsto{Q_A} \eta_A\left(\phi_A(a; \theta), v\right)$$
$$((a; \theta); v) \xmapsto{Q_B} \eta_B\left(\eta_A(\phi_A(a; \theta), v_B) \times \phi_B(a; \theta), v\right),$$

where each $\eta_f : [0, 1]^2 \to [0, 1]$ is assumed smooth in both inputs and strictly increasing in its first input.[4] We further assume that $\eta_A(\phi, v_A) = \eta_B(\phi, v_B) = \phi$ for all $\phi \in [0, 1]$, so

[4] If a given η_f is increasing in its second input—*i.e.,* in its location downstream—then we are modeling the case where water improves as it flows downstream, thanks to rain or new sources or whatever the case

that behavior at the facilities provides an intercept for the drift functions. Pointwise water quality takes the form

$$q_v(a;\theta) = \begin{cases} Q_A\left((a;\theta);v\right), & v < v_B, \\ Q_B\left((a;\theta);v\right), & v \geqslant v_B \end{cases}.$$

A general example is depicted in Figure 1. The basic idea here is that each facility takes water

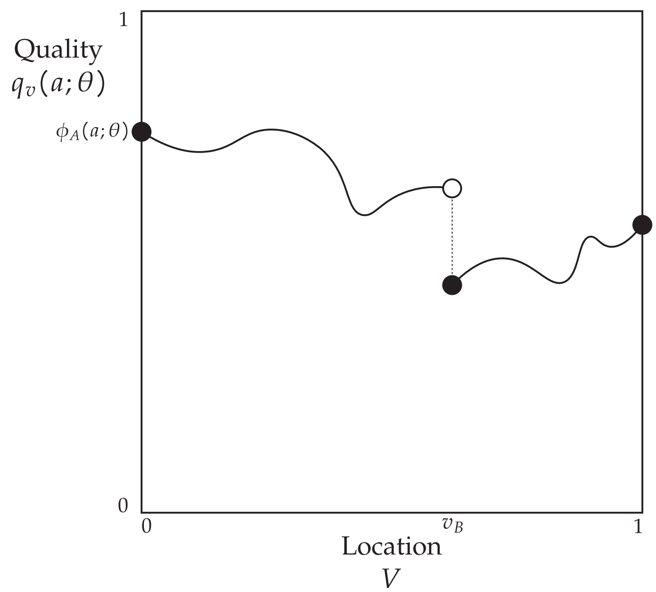

Figure 1. Sample $q_v : A \times \Theta \to [0,1]$.

at a given quality level and shifts its intercept for the next region downward depending on the compliance level there. Facility A therefore shifts quality down from its initial condition $q = 1$, and Facility B shifts water quality down from $\eta_A\left(\phi_A(a;\theta), v_B\right)$, which is what the water quality would be at v_B were Facility B perfectly compliant.

Finally, preferences. The regulator is concerned with water quality across V, but she must pay quadratic costs for her efforts:

$$u_R(e,c;\theta) = \int_0^{v_B} Q_A\left((a;\theta);v\right) dv + \int_{v_B}^1 Q_B\left((a;\theta);v\right) dv - \frac{\kappa}{2}\left(e_A^2 + e_B^2\right),$$

may be. But, since environmental impact might transcend the water itself—*e.g,* local flora and fauna may vary in their sensitivity along the river—we allow for nonmonotonicities in v, as well.

where $\kappa \in (0,1]$ scales the regulator's cost of effort. The facilities are concerned with the benefits of noncompliance and the likelihood that they are caught. If caught, they pay a penalty $\pi \in (0,1]$; if not, they enjoy the benefits of noncompliance. All told, Facility f's utility function takes the von Neumann-Morgenstern expected utility form

$$Eu_f(e,c;\theta) = (1 - p_f(e,c))\,(1 - c_f) - p_f(e,c)\pi.$$

We now simplify the analysis considerably with three intuitive lemmas that highlight the basic tension driving the application. First, we see that there cannot exist equilibria wherein the facilities comply perfectly.

Lemma 6 (Nobody's Perfect)

For both facilities $f \in F$, $c_f^* < 1$.

The logic here is straightforward: if a facility were perfectly compliant, then the regulator would spend no effort there, which in turn would incentivize the facility to comply less, breaking equilibration. This raises questions about how the regulator behaves at the two facilities. Next, we see that the regulator is constantly vigilant save for the limiting case where the downstream facility is situated exactly at the bottom of the watershed.

Lemma 7 (Vigilance Save for the Bottom)

$e_A^* > 0$ *and* $(e_B^* > 0 \iff v_B < 1)$.

In other words, the regulator is always willing to work so long as there are some *downstream* benefits of doing so. In the limit, effort disappears when $v_B = 1$.[5] Finally, we record the simple notion that if a regulator expends zero effort at a facility, then the facility complies not at all.

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[5] This result depends on our equal-weight-across-jurisdiction approach to incentivizing effort on the regulator's part. One could amend the regulator's utility function to allow for nontrivial point mass at a finite set of points, including the downstream facility's location. In this case, the "race to the bottom" as $v_B \uparrow 1$ will yield a limit at an effort level that equilibrates the local (downstream) marginal benefit in quality and the marginal cost of effort.

Lemma 8 (When the Cat's Away)

For both $f \in F$, $e_f^* = 0 \implies c_f^* = 0$.

Thus, the conditions that lead to zero effort also lead to zero compliance. However, the converse need not be true: a given facility might comply minimally while the regulator inspects in the name of mitigating the deleterious environmental consequences of extreme noncompliance.

With these three lemmas in place, we can now state the main result of this section: as the downstream facility is moved closer to the limit of the regulator's jurisdiction, the regulator eventually expends negligible effort there, and the facility eventually exhibits negligible compliance.

Proposition 9 (Convergence to the Bottom)

Let $\left(\theta^{(m)}\right) \in \Theta^{\infty}$ *be a parameter sequence that converges to some* $\overline{\theta} \in \Theta$ *featuring* $v_B = 1$. *Then for any* $\varepsilon > 0$, *there exists some* $\overline{m} \in \mathbb{N}$ *such that*

$$\overline{m} \leqslant m \implies \max\left\{e_B^*\left(\theta^{(m)}\right), c_B^*\left(\theta^{(m)}\right)\right\} < \varepsilon.$$

Proposition 9 informs our first hypothesis (stated in the next section), and its logic is straightforward. Given the myriad possibilities regarding how polluted water impacts the environment downstream, we cannot make any promises that regulators expend less effort as the downstream facility moves further downstream; after all, it would well be that v_B is very close to 0, so that there is little space between the two facilities. In such cases, there exist subspaces of the parameter space wherein e_B^* *increases* as v_B moves downstream. However, Proposition 9 tells us that this can only go so far: eventually, the upstream regulator cannot concern themselves with the downstream facility given the small area it influences downstream.

1.1.2 Upstream Regulators Work Harder When They Control More

We now study the relationship between watershed autonomy and regulatory effort.

We continue to study two facilities $F = \{A, B\}$, but now we have two regulators, $R = \{1, 2\}$. The facilities are located at $v_A = 0$ and $v_B > 0$, and V is partitioned into $\mathcal{J} = \{[0, \widetilde{v}), [\widetilde{v}, 1]\}$, where $\widetilde{v} \leqslant v_B$ tells us what proportion of the watershed V is under Regulator 1's control. Regulator 1 (resp. 2) chooses e_A (resp. e_B) in $[0, 1]$, and each facility f chooses c_F in $[0, 1]$. To keep the focus on the regulators' incentives, we maintain the functional forms for probability of detection.

We now provide a straightforward parameterization of the model's environmental aspects. We keep the instantaneous effects ϕ_f the same but explicitly parameterize pointwise quality via the function

$$\eta_f(\phi, v; \theta) = \phi + \lambda e^{\beta\phi} (v - v_f)^{\gamma},$$

where $\lambda \geqslant 0$ provides a baseline for the speed of environmental improvement downstream; $\beta \geqslant 0$ tells us how much the instantaneous environmental effect of the most recent upstream facility influences that velocity; and $\gamma \in [0, 1]$ provides the shape of the improvement function. For example, if $\beta = 0$ and $\gamma = 1$, then water improves at a constant linear rate with slope λ. Naturally, $\lambda = 0$ means water quality does not improve at all as it flows. In terms of the analysis, the most important property encoded by this η_f parameterization is that *water quality weakly improves as we move further from non-compliant facilities.*

As for preferences, we keep the von Neumann-Morgenstern expected utilities for the facilities. Regulator 1's preferences take the form

$$u_1(a; \theta) = \int_0^{\widetilde{v}} Q_A(a; \theta) dv + \alpha \left(\int_{\widetilde{v}}^{v_B} Q_A(a; \theta) dv + \int_{v_B}^{1} Q_B(a; \theta) dv \right) - \frac{\kappa e_A^2}{2},$$

where $\alpha \in [0, 1]$ tells us how much Regulator 1 values water quality in Jurisdiction 2. We assume $\alpha \leqslant 1$, suggesting that Regulator 1 cares more about Jurisdiction 1 (her own jurisdiction) at least as much as Jurisdiction 2 (the jurisdiction immediately downstream).

Regulator 2's preferences take the simple form

$$u_2(a;\theta) = \alpha \int_0^{\widetilde{v}} Q_A(a;\theta)dv + \int_{\widetilde{v}}^{v_B} Q_A(a;\theta)dv + \int_{v_B}^{1} Q_B(a;\theta)dv - \frac{\kappa e_B^2}{2},$$

so that α also tells us how much Regulator 2 cares about Jurisdiction 1.

This game still has at least one pure-strategy Nash equilibrium, and Lemmas 6 to 8 continue to obtain.[6] We therefore are in position to state our main equilibrium result.

Proposition 10 (Upstream Agents Work Harder When Responsible for More)

In any Nash equilibrium of the game described in this section,

$$\frac{\partial e_A^*}{\partial \widetilde{v}}(a;\theta) \geqslant 0.$$

If $\alpha < 1$, this inequality holds strictly.

Proposition 10 informs our second hypothesis, and its logic is also straightforward. The location $\widetilde{v}$ is the bottom of Regulator 1's facility, and it falls somewhere upstream of Facility B, which is located at the point $v_B > \widetilde{v}$. The space between $\widetilde{v}$ and v_B is, in a sense, "dead"—the environmental quality at points $v \in [\widetilde{v}, v_B) \subset J_2$ is determined solely by behavior at Facility A, but Regulator 1 is less incentivized to work hard at Facility A than she would be were there no such "dead" space.

We now turn to evaluating our two hypotheses summarized below:

Hypothesis 1

As the area of a shared resource controlled by an agent increases, the agent will produce greater regulatory effort in cases where their regional office is geographically upstream from the office with whom she shares responsibility.

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[6] Lemma 7 requires the modification that each regulator shirks when their respective facility approaches their respective jurisdiction's bottom.

Hypothesis 2

As the area of a shared resource controlled by an agent increases, the agent will produce greater regulatory effort for facilities that are further from the nearest downstream border.

In the next sections, we consider the case of water pollution in the U.S. and then discuss our empirical research design to test these hypotheses.

2 Water Pollution Control and Spillover in the United States

The management of U.S. water pollution provides an ideal empirical setting to study spillover problems that arise when environmental resource and governance boundaries do not match. The primary federal statute that addresses discharges of water pollutants into U.S. waterways is the U.S. Clean Water Act (CWA).[7] Similar to other major U.S. federal pollution control statutes, the CWA is largely implemented under a model of cooperative federalism in which the federal government (*i.e.,* the U.S. Environmental Protection Agency, or EPA) has the principal authority to set standards, but then hands over implementation responsibilities to willing state governments. More specifically, for point sources of pollution (*e.g.,* factories, power plants, municipal wastewater plants) that release effluent directly into U.S. waters, the EPA sets technology-based limitations. As a backstop to these limits, the CWA obligates states to set water quality standards, which may result in further effluent limitations so as to assure that a specific water resource is achieving its designated uses (*e.g.,* drinking, fishing, swimming, etc.).

Of most relevance for our study is that the EPA has largely delegated implementation of the CWA to state agencies. State environmental offices carry out the largest share of permitting, compliance monitoring, and enforcement activities for the hundreds of thousands

[7] A separate U.S. law—the Safe Drinking Water Act—addresses the quality of drinking water.

of individual sources of water pollution in the United States. By one estimate, over 90% of the environmental enforcement in the United States is generated by state pollution control agencies rather than the EPA (ECOS 2001; 2006). Given inevitable variation in how states decide to pursue these activities, it is no surprise that states feature prominently in scholarly treatments of U.S. environmental regulation (*e.g.,* Hunter and Waterman 1996; Konisky 2007; Lowry 1992; Potoski 1999; Ringquist 1993; Wood 1991, 1992). In fact, much of what we have learned over the past three decades about the effects of politics, economics, and administrative features on U.S. environmental implementation rests on the foundation that states are the most relevant level of government for analysis.

Despite this considerable attention, scholars have black-boxed important institutional features of state environmental agencies, including their geographic organization. Most states do not implement policy via the state capital, but rather they have decentralized it to regional offices distributed throughout the state. The logic of this devolution is driven, at least in part, by a desire to manage demanding workloads efficiently and to be more responsiveness to local needs (Woods and Potoski 2010). Nevertheless, extant research in environmental regulation has virtually neglected state regional offices as unique policy delivery institutions in their own right (Reenock, Konisky and Uttermark (2022) is an exception). In so doing, scholars have not examined the extent to which this geographical carving up of state policy implementation induces coordination problems. Dissecting administrative responsibility of a resource introduces two intimately-linked geographic challenges for regulation. It creates multiple parties responsible for the resource's management, and in doing so, it also situates at least one of these parties as being downstream from the other.

To illustrate this situation, consider Figure 2 below, which overlays U.S. watershed boundaries with state regional water pollution control offices. It is rare for state regional offices to follow watershed boundaries. Instead, watersheds, and therefore their associated rivers, typically transcend two or more regional offices. In most cases, states have demarcated their regional offices by groupings of coterminous counties in a manner that does not account for watershed boundaries. As we show below, dissecting watersheds induces at least two In fact, for all watersheds in the figure, the average percentage of a watershed fully contained within a state regional office is 75% with a standard deviation of 27%. It merits mentioning that, state boundaries, of course, also transcend watershed boundaries. However, the types of problems that arise from interstate management of water resources have received more attention in the literature (Bowman and Woods 2007; Heikkila and Schlager 2012; Schlager and Heikkila 2009; Woods and Bowman 2018) than the types of intrastate issues emphasized here.

To further illustrate, Figure 3 displays regional office and watershed boundaries for California, which stands alone in its effort to consider watershed boundaries when drawing its regional offices boundaries. The nine regional offices in California have boundaries that nearly fully encompass their covered watersheds. In California, the average percentage of a watershed contained within a state regional office is 99% with a standard deviation of 3.0%. Other state agencies, by contrast, routinely dissect watersheds. Georgia and Wisconsin, in the other two panels, are not as mindful of watershed boundaries. In Wisconsin, the average watershed amount that is fully contained within a state regional office is only 72%, with a standard deviation of 26%. Watershed dissection is even more pronounced in Georgia where the average amount of a watershed that is fully contained within a state regional office is only 62%, with a standard deviation of 29%.

But dissecting a watershed also induces another challenge: directionality. Discharges of pollutants into waterways may not only diminish proximate water quality, it may also adversely affect water quality in downstream locations. A closer look at the case of Georgia illustrates this point. In Figure 4, we have added major rivers and the location of point sources water pollution regulated under the CWA to the map. Consider the area highlighted in red. This watershed is split between Georgia's Mountain District office (to the north) and its West Central District Office (to the south). The major river in this watershed is the Flint River, and it flows from north to south. In this case, agents in the upstream Mountain

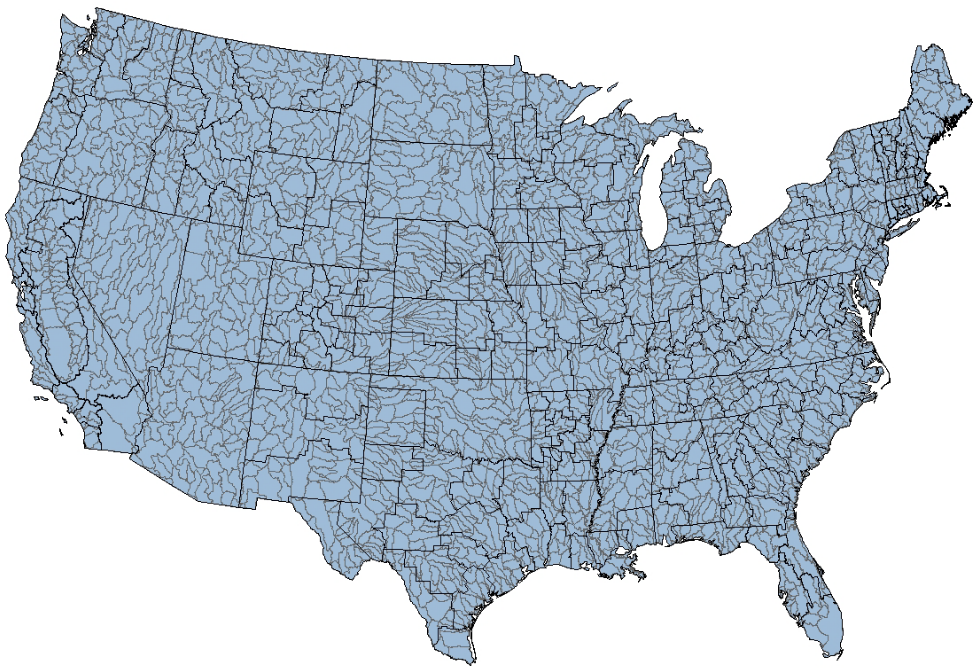

Figure 2. State Regional Offices and Watershed Boundaries

District office may have incentive to exert less enforcement effort on facilities located nearest the downstream regional office border.

How might agents responsible for regulating facilities under the CWA respond to the two geographic challenges induced by dissecting an environmental resource? Our model provides two expectations, which, in the next section, we discuss our research design that we employ to test these hypotheses.

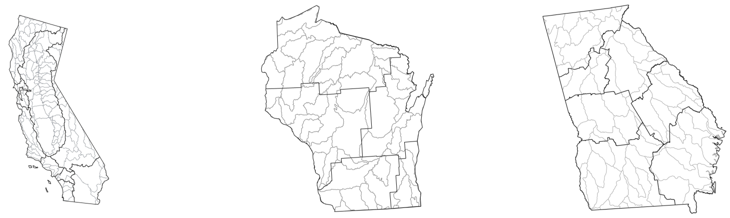

Figure 3. *California, Wisconsin, and Georgia state environmental agency water division regional offices.*

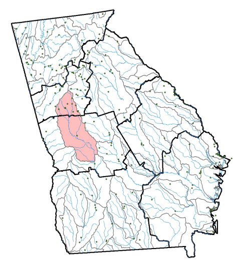

Figure 4. *Georgia Environmental Protection Division's 7 administrative water regions and overlaid watersheds. Circles are major water facilities. Flint River watershed is shaded region.*

3 Empirical Analysis

To examine our propositions, we created an original dataset that combines administrative data on regulatory compliance and enforcement, watershed boundaries, streamline and elevation data,[8] and state administrative agency boundaries. We discuss each in turn.

Regulatory Compliance and Enforcement. The EPA maintains extensive historical records on facility-level compliance with most major pollution control laws, as well as regulatory actions taken by federal and state officials to enforce these laws. In the case of the CWA, we use data from the EPA's Integrated Compliance Information System-National Pollution Discharge Elimination System (ICIS-NPDES) dataset.[9] The ICIS-NPDES archives facility-level

[8]As described more below, each of the datasets we used come from the USGS National Hydrography Dataset collection.

[9]These data are available to download at the following EPA website: `http://echo.epa.gov/tools/data-downloads`.

violations of and compliance with the CWA (*i.e.,* not all violations result in an determination of noncompliance as defined by EPA guidance), and individual enforcement actions taken by the EPA and state government agencies (*e.g.,* compliance monitoring inspections, punitive measures). The data include a diverse set of facilities that are required to have NPDES permits under the CWA (under the law, any point source discharging pollutants directly into a U.S. waterway is required to have a NPDES permit), but, since reporting is only required for "major" NPDES sources, we limit the scope of our study to these facilities.[10] During the time period of this study, there were about 6,700 facilities with major NPDES permits, although we analyze a slightly smaller number (about 6,400) because some major facilities are located in states that the EPA had not yet delegated authority to implement the CWA (Idaho, Massachusetts, New Hampshire, and New Mexico), and because of some missing data.[11]

Due to data constraints on state regional office information, our timeframe is limited. As such, we create several measures using the ICIS-NPDES data for the years 2001-2014. First, the dependent variables we analyze come from the regulatory output data included in ICIS-NPDES. Specifically, we create annual counts of state-led inspections directed toward each major NPDES permitted facility, distinguishing between sampling inspections (*i.e.,* inspections in which government officials conduct independent sampling of a facility's discharges) and non-sampling inspections (*i.e.,* inspections that do not include independent sampling and reflect a review of facility records).[12] We present the results for sampling inspections in text as they reflect a higher level of agents' detection effort; results for non-sampling

[10]Major NPDES sources include large publicly owned treatment works, privately owned treatment works, industrial dischargers, concentrated animal feeding operations, and other facilities deemed significant by EPA, state, and/or tribal officials.

[11]Included in the analysis are major facilities regulated by the CWA who have either active or expired permits. We assume facilities with expired permits continue to operate, unless their permit has been terminated. Terminated facilities are dropped. In addition, we assume that included facilities were operational for the entire duration of the study period.

[12]The EPA also conducts inspections, but these are mostly in an oversight capacity, except for in the four states to which the EPA has not delegated authority to implement the NPDES program: Idaho, Massachusetts, New Hampshire, New Mexico. In our time period of study, Alaska was delegated authority in 2008, Arizona in 2004; Maine in 2001.

inspections, which reflect a lower level of agent effort are reported in the Appendix. These measures are frequently used in the social science literature to capture the regulatory effort of government agencies to enforce the CWA (Gray and Shadbegian 2004; Helland 1998; Konisky 2007; Konisky and Reenock 2013; Scholz and Wang 2006).

The ICIS-NPDES data also include quarterly determinations of a facility's noncompliance status with the CWA. In particular, the EPA tracks two types of noncompliance: reportable noncompliance and significant noncompliance. Significant noncompliance is the more serious designation, and can be triggered by effluent violations (*i.e.,* discharges that exceed permitted limits), failure to submit a discharge monitoring report, violation of a previously-set compliance schedule, or a violation identified during a government inspection. Reportable noncompliance are instances of noncompliance that do not rise to the level of significant noncompliance. In the analysis that follows, we create dichotomous, annual measures of each noncompliance type for each major NPDES facility.

In sum, we create a facility-year level dataset of compliance and regulatory actions for about 6,400 major NPDES sources. These facility-level data are then combined with the geographic data we describe next.[13]

Regional Office Boundaries, Watershed Boundaries, and Downstream Border Distance. To examine our hypotheses regarding the dissection of watershed boundaries and policy coordination, we collected four additional sets of geographic data. First, we obtained information on the geographic organization of each state agency, which we compiled in earlier research from state agency websites or other documents we collected from contacting state officials. This information was confirmed in telephone interviews with officials in each state agency. These are the data we previously presented in Figure 2. We then used GIS software to delineate the jurisdiction of each office.[14]

[13]The facility information in ICIS-NPDES do not include precise geospatial identifiers (i.e, longitude and latitude) for facilities. For this reason, we used geospatial information available for facilities contained in EPA's Facility Registry System (FRS) and them merged this with the ICIS-NPDES data. These datasets contain different lists of major NPDES facilities, so those studied here are those that were 1) included in FRS and 2) had matching compliance and enforcement information in ICIS-NPDES.

[14]For most states, this is a straightforward task because regional office boundaries correspond to other

Second, we collected information on watershed boundaries from the U.S. Geological Survey's (USGS) Watershed Boundary Dataset. The USGS classifies all watersheds in the United States using a numerical coding system that assigns each a unique hydrologic unit code (HUC). In our analysis, we use cataloging units, which are geographic areas that represent part or all of a surface drainage basin, a combination of drainage basins, or a distinct hydrologic feature. Each watershed represents a natural topographical basin within which surface water drainage exits via a single outlet. There are 2,264 such cataloging units in the United States.

Our measure of watershed intersection accounts for the *degree* of control that an agent has over a watershed. This formulation is more consistent with our theoretical propositions than treating dissection as a dichotomous condition, since we posit that the degree of effort exerted by an agent depends on how much a watershed is split across administrative regions. We measure watershed dissection as the watershed's proportion that is contained within the boundaries of a given regional office, which we delineate using geographic area (measured in square miles). Of the 2,111 watersheds in the continental United States, about 15% are contained wholly within a single state regional office. In these cases, our dissection metric is equal to one (*i.e.,* agents control the full area of the facility's watershed). Many of these are watersheds located within states that do not makes use of regions – the entire state is a single administrative region. There is considerable variation in the proportion of a watershed area managed by regional officers. For the facilities in our data, the overall mean and standard deviation of watershed dissections are 0.74 and 0.28, respectively. This measure is the key variable we use to test our first hypothesis.[15] The remaining 85% are intersected in some way by regional office boundaries. Of the approximately 6,400 facilities in our data, about 23% are located in watersheds that are not subdivided by regional state office boundaries.

To determine which regional office is upstream or downstream for cases of shared environ-

political boundaries such as counties or towns. In the small number of cases where the regional office boundaries fall along watershed or other boundaries or are comprised of partial counties, we delineated each regional office boundary using ArcGIS tools.

[15]This percentage increases to about 20%, if watersheds that are 99% wholly contained are included.

mental resources, we collected and processed two additional sets of data. First, we used the USGS Flowline Dataset to delineate the major stream in each watershed. We then overlayed elevation measures from the USGS National Elevation Dataset to determine the elevations along each major stream. Using this information we then calculated the maximum elevation height for the stream within each regional office-watershed segment. We then created a variable coded one if the elevation value for a given regional office-watershed segment exceeded that of each of the other regional offices sharing jurisdiction over the watershed. Alternatively, if the elevation value for or a given regional office-watershed segment is less than that for the other regional offices, we coded the variable as zero.[16] With this dichotomous coding, therefore, a value of one represents "upstream," and a value of zero represents "downstream."

We also create a variable "downstream border distance," to asses whether agents distinguish between facilities located far from a downstream border and whose effluent is more likely to be retained in their jurisdiction and facilities located near a border and whose effluent is more likely to spillover into a neighboring region. This measure is calculated as the distance, as the crow flies, between the facility and the closest administrative border that is downstream from it. The average distance to the nearest downstream border is 9.78 miles, with a standard deviation of 8.97 miles. Nearly 25% of facilities in our data are less than a .25 miles from a downstream border.

For both of the prior variables, streamflow direction and downstream border distance, we only calculate these measures for watersheds that are shared with another administrative region. The 15% of watersheds that are fully contained within a region are dropped from our analysis. This is because a fully-contained watershed that is either is up or downstream from another watershed within the same region elicits no effort dilemma for an agent – the watershed's effluent is fully contained in the region regardless of streamflow direction.

[16] Excluded are cases in which the elevation value neither exceeded nor was less than all other values, we coded the variable as zero, as well as cases where a watershed is fully within a single regional office, and a limited number of cases where there was some missing elevation information in the original USGS National Elevation Dataset. Excluding these cases is not problematic since incentives for a regulatory office to exert more or less effort should be unaffected in these circumstances.

Only watersheds shared with other administrative regions elicit the spillover dilemma we are investigating. Given that our results may be sensitive to what constitutes a "fully contained" watershed, we consider three thresholds of this delineation. For our analyses, we report three estimates for each threshold of what constitutes a fully-contained watershed. The highest threshold, 1.0, requires 100% of the watershed to be fully contained within a state administrative region. However, we also include analyses in which this threshold is relaxed to .95 and .90 of the total watershed.

3.1 Estimation Strategy

To examine the relationship between watershed control, streamflow direction and state regulatory enforcement actions, we estimate GLS random-intercept linear regression models,[17] with robust standard errors clustered on facilities, of the following basic form:

$$\begin{aligned} I_{it} = &\beta_1 \text{Area}_i + \beta_2 \text{Upstream}_i + \beta_3 \text{Area}_i \times \text{Upstream}_i \\ &+ \boldsymbol{Z}_{it}\boldsymbol{\gamma} + \nu_i + \tau_t + \epsilon_{it}, \end{aligned}$$

where i indexes facilities and t indexes years. The dependent variable I_{it} is one of our measures of state inspection actions. On the right hand side, Area_i is watershed-segment level measure that reflects the proportion of the watershed controlled by the regional officer, and Upstream_i is a watershed-segment level measure that reflects whether the segment is upriver. These features are time-invariant for the facilities in our data. Per the theory above, the interaction of these two variables is also included. $\boldsymbol{Z}_{it}$ is a vector of control variables discussed below. We allow for random intercepts at the facility level, ν_i is a random effect for facilities and τ_i represents fixed effects for years. Last, $\epsilon_{ijk\ell t}$, represents the error term.

To examine the relationship between watershed control, downstream border distance and state regulatory enforcement actions, we estimate the same GLS models but with a new

[17] Included in the Appendix are additional population averaged models which allow the facility-level errors to be serially correlated as an AR1 process. Both estimators produce similar results.

interaction term, of the following basic form:

$$I_{it} = \beta_1 \text{Area}_i + \beta_2 \text{Downstream Border Distance}_i + \beta_3 \text{Area}_i \times \text{Downstream Border Distance}_i + \boldsymbol{Z}_{it}\boldsymbol{\gamma} + \nu_i + \tau_t + \epsilon_{it},$$

where i indexes facilities and t indexes years. The dependent variable I_{it} is one of our measures of state inspection actions. On the right hand side, Area_i is watershed-segment level measure that reflects the proportion of the watershed controlled by the regional officer, and $\text{Downstream Border Distance}_i$ is a facility level measure that reflects the distance from the facility to the nearest downstream administrative region border. These features are time-invariant for the facilities in our data. Per our theoretical expectations, we also include the interaction of these two variables. The remaining elements of the model are similar to the equation above.

We address three possible sources of endogeneity: omitted variable bias, sample selection, and reverse causality. To minimize the threat of endogeneity due to omitted variable bias and sample selection, we include a large suite of control variables to adjust for any possible factors that may incentivize firm location choice and firm compliance decisions. To account for confounding factors related to regulatory enforcement outcomes, our models include numerous facility, regional, and state level control variables. At the facility level, we include facility age (based on the date the facility received its first NPDES permit), a series of dichotomous variables to distinguish publicly owned treatment works (POTWs), and industrial dischargers that are either in the electric power sector or in the manufacturing sector. In addition, we created “neighborhood" level demographic measures for each facility. Specifically, we used an areal apportionment method common to the environmental justice literature (Konisky and Schario 2010; Mohai and Saha 2006), in which, with GIS software, we estimate the percentage of the population within a one-mile radius circle of each facility that is African-American, Hispanic, below the federal poverty level, and college educated.

Also at the facility level, we control for whether the facility was in either reportable or significant noncompliance status during the year, since regulatory enforcement activity is likely to be greater if a facility is determined to be in violation of the CWA.

At the region office level, we include two variables to account for state regulators' overall task environment: the total number of major NPDES facilities in the region and the total number of all (major and minor) NDPDES facilities in the region.[18] We include similar measures at the level of regional office-watershed section; this is the unit of geography representing the overlap of the regional office and watershed boundaries. These measures control for the more local task environment facing regulatory agents.

Last, we control for a set of state and federal level factors that are commonly included in models of state regulatory enforcement. To account for state economic and political factors that may influence overall enforcement efforts, we use: state unemployment rate, gross state product, the partisan identification of the governor (coded one for a Democrat, and zero otherwise), and the percentage of the lower chamber of the state legislature that are Democrats. In addition, we limit our analysis to states delegated authority to implement the CWA by the EPA. At the federal level, we include a dummy variable coded one for the George W. Bush Administration and zero for the Barack Obama Administration, a variable to capture differences in party control of the U.S. Congress (coded one for unified Republican control (2003-2006), negative one for unified Democratic control (2008-2010), and zero otherwise), and dummy variables for EPA regional offices.

On threats of endogeneity due to reverse causation, we believe that it is a reasonable assumption that enforcement decisions have no impact on the proportion of the watershed under administrative control nor whether that watershed is upstream/downstream. This is due to the fact that administrative boundaries, whether intra-state or inter-state, are temporally stable in our data. These state administrative regions were put in place in the

[18] Geospatial data available from the EPA does include complete latitude and longitude information for all minor NPDES facilities; information is missing for about 20% of these minor facilities. In subsequent work, we will attempt to specify the location of these sources based on their street address.

Table 1. Parameter Estimates Estimating Regulatory Actions

	Sampling Inspections		
	(Area $\leqslant$ 1.0)	(Area $\leqslant$ .95)	(Area $\leqslant$ .90)
Area	-0.032	-0.020	-0.061*
	(0.0286)	(0.0301)	(0.0342)
Upstream	-0.055**	-0.047*	-0.080***
	(0.0245)	(0.0253)	(0.0275)
AreaXUpstream	0.081**	0.061*	0.142***
	(0.0340)	(0.0371)	(0.0444)
rho (intraclass correlation)	0.151	0.156	0.155
Groups	3701	3242	2651
Observations	48095	42128	34445

Note: Coefficients are estimates from a linear random-effects GLS regression with robust standard errors in parentheses. EPA region and year dummies not displayed. Two-tailed tests. Statistical significance: ***$p < .01$, **$p < .05$, *$p < .10$.

1970s and have essentially remained constant as the main enforcement delivery mechanism to the present. While regional offices have shifted in a few states over time, these changes are rare and minimal in their impact on a state's overall regional office makeup.

3.2 Results

We report complete model estimates for both empirical exercises in the Appendix. Table A.1 reports the estimated relationship between regulatory officer agency and a shared watershed's relative upstream location while Table A.2 reports the estimated relationship between regulatory officer agency and a facility's relative upstream distance from the closest downstream border. Both empirical investigations offer support for our expectations.[19]

For each of the models below, we report three sets of estimates with different thresholds of what constitutes a fully-contained watershed. The highest threshold, 1.0, requires 100% of the watershed to be fully contained within a state administrative region. The remaining thresholds reduce this requirement by 5% each at .95 and .90 proportion of the total, respectively.

[19] We also include in the Appendix tables, A3 and A4, the respective estimates of the population averaged models that allow for AR1 serial correlation in the errors. The results reproduce our random effects estimates.

Table 1 displays the key coefficients from the full inspections models that provide a test of whether regulatory officers' effort is jointly motivated by enhanced control over their watershed and the relative location of their watershed in the network. The estimates suggest that the proportion of the watershed under regional officers' control motivates their behavior but is conditioned by the policy context of their responsibilities. The association between officer agency (area) and detection effort is null (or negative) for downstream agents but is positive for upstream agents. To illustrate this conditional relationship, we consider the marginal effect of the area controlled over policy context in a series of marginal effect plots. Figure 5 displays the marginal effect of the proportion of area controlled plotted over streamflow direction with Panels A, B and C showing the effects for different thresholds of what constitutes a fully-contained watershed at 1.0, .95 and .90 proportion of the total, respectively.

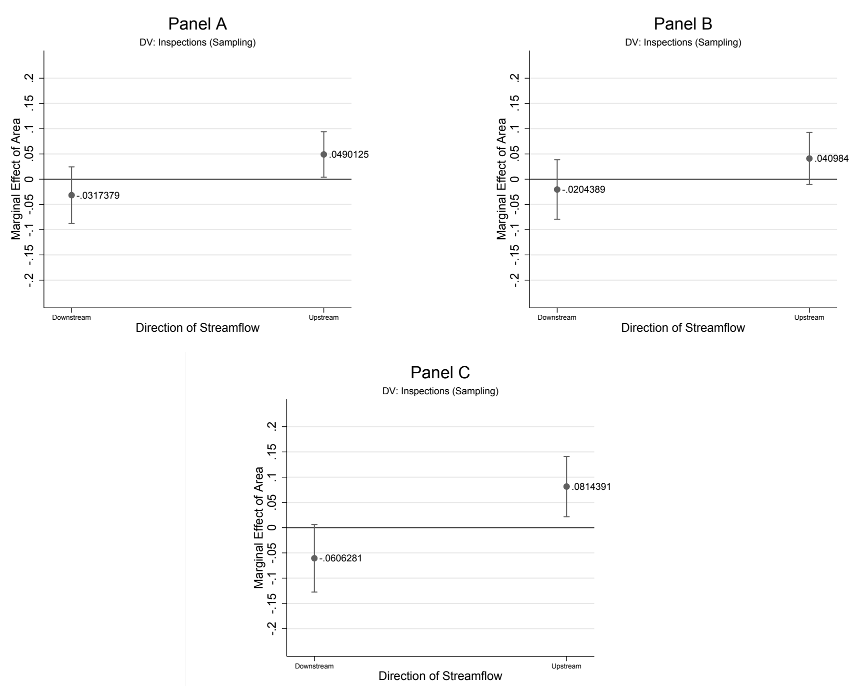

Figure 5. *The marginal effect of the proportion of the watershed controlled over being downstream vs. upstream by different enforcement outputs.*

On the left-hand side of each plot we see that controlling one's watershed has no association with detection effort when an agent is located downstream from another watershed.

Table 2. Parameter Estimates Estimating Regulatory Actions

	Sampling Inspections		
	(Area ⩽ 1.0)	(Area ⩽ .95)	(Area ⩽ .90)
Area	-0.0849**	-0.0601	-0.0129
	(0.0377)	(0.0415)	(0.0506)
Downstream Border Distance	-0.0048***	-0.0044***	-0.0037**
	(0.0015)	(0.0015)	(0.0017)
AreaXDownstream Border	0.0062***	0.0053**	0.0035
	(0.0019)	(0.0021)	(0.0025)
rho (intraclass correlation)	0.163	0.171	0.173
Groups	3891	3460	2955
Observations	50565	44962	38397

Note: Coefficients are estimates from a linear random-effects GLS regression with robust standard errors in parentheses. EPA region and year dummies not displayed. Two-tailed tests. Statistical significance: $^{***}p < .01$, $^{**}p < .05$, $^{*}p < .10$.

The marginal effect of area for downstream facilities is null or negative, suggesting that increasing control over the watershed either has no effect or lowers sampling inspections among downstream facilities. Focusing on the right-hand portion of the panels, we see that the marginal effects of agency over one's watershed is associated with greater detection effort among upstream facilities (The error in Panel B is large enough, however, to straddle the x-axis, but the estimated coefficient is still positive). The substantive size of this effect reduces inspections by approximately .05-.08 inspections, depending upon the model.

Table A.2 reports the complete conditional models that assess whether an agent's effort is jointly motivated by enhanced agency over their watershed and the relative distance of a facility to the downstream border. Table 2 displays the key coefficients from these models. Similar to above, the estimates again suggest that the proportion of the watershed under regional officers' control motivates their behavior but is conditioned by the policy context of their responsibilities. The association between officer agency (area) and detection effort is null (or negative) agents when facilities are nearest a downstream border. Detection effort is, however, positively associated with authority over facilities that are located deeper within the watershed.

Figure 6 displays the marginal effect of the proportion or area controlled over a facility's distance from the closest downstream border. The plots illustrate how inspection effort varies over both having agency over one's watershed and how close a facility is to a downstream border. When facilities are nearest a downstream border (the left side of the figures), the marginal effect of area is either negative or null, suggesting that increasing agency over the watershed either lowers or has no association with inspections or detection effort. The marginal effect of area however is positive for facilities that are sufficiently 'upriver' from the nearest border. This is because agents can be held responsible for the effects that these facilities may have upon the local watershed. The right-hand side of the panels suggest that as facilities are located well-within the watershed, enhancing agent's control over their watershed incentivizes them to exert greater detection effort. The substantive size of this effect ranges anywhere between 0.5 to 2 additional inspections per facility per year, depending upon the distance to the downstream border.

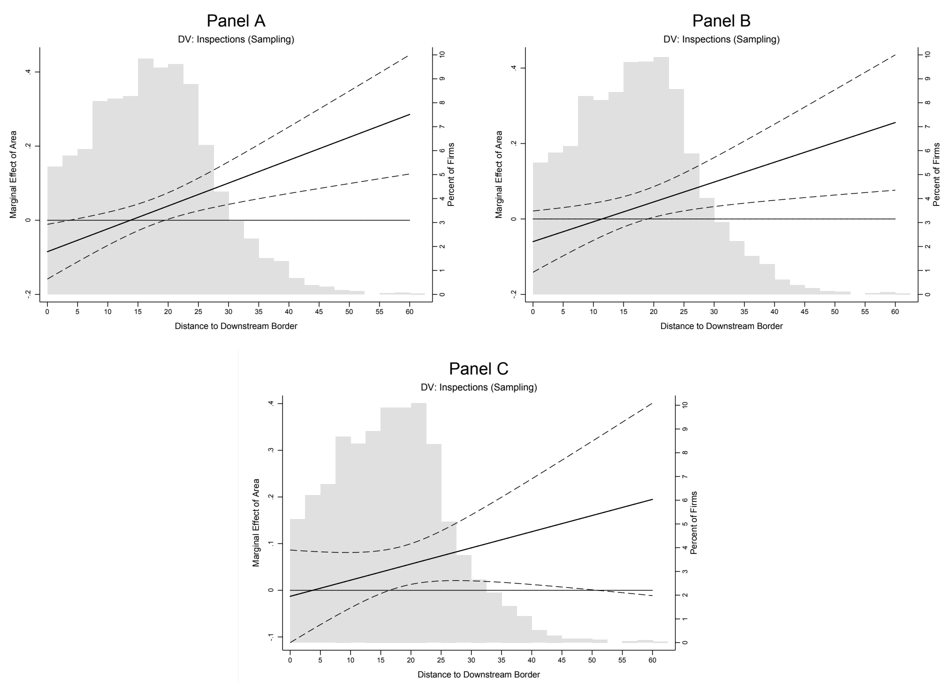

Figure 6. *The marginal effect of the proportion of the watershed controlled over facility stream location by different enforcement outputs.*

4 Discussion

Policy scholars have long debated the merits of whether to devolve implementation authority to subunits. Our research underlines the value in considering how such devolution proceeds by highlighting how certain institutional designs may exacerbate public goods spillover in a policy arena. When devolution fragments a policy space, it induces joint policy-production relationships, where agents experience spillover of the public good being generated. To manage the tradeoffs inherent in such fragmented policy spaces, policy leaders must recognize the importance of not only the level and nature of fragmentation in the space, but also the distinct motivational levers at their disposal to reward agents' private and public effort.

Our analysis expanded on prior literature by focusing on regulatory detection effort and incorporating the degree of resource fragmentation. The model reveals that regulatory effort varies across facilities based on their proximity to jurisdictional borders and the size of their jurisdiction. It provides valuable insights into the factors influencing regulators' decision-making processes and highlights the role of network structures in shaping regulatory outcomes. If our account is correct, then we have preliminary evidence that under certain conditions regulatory detection effort is undersupplied, not due to the political demands of elected officials or local stakeholders, but because of the misaligned incentives that particular institutional configurations offer administrative agents. By addressing these gaps in the literature, our model identifies the factors that influence regulatory effort and the potential consequences of inadequate coordination and contributes to the broader understanding of effective governance and policy delivery.

Our paper's contributions, while relevant to environmental pollution, are not limited to them. Our model can be extended to any context where a public good is delivered in an interrelated network that fragments a resource. Consider, for example, that in environmental applications, the relevant forcing variables that order the flow of effort is gravity with water pollution, or prevailing winds with air pollution. But the relevant forcing variable could take on different forms in other settings. For example, the forcing variable could also be time. Under this interpretation, we could imagine extensions to educational policy where resource fragmentation could present over course sequences (e.g. Calculus I, Calculus II, Calculus III). In this applications, teacher effort at a given level would be conditioned by the temporally upstream teacher effort provided at lower levels. Under yet another interpretation, the forcing variable could be geographic distance between neighborhoods. Under this interpretation, we can imagine extensions to home values where resource fragmentation could present as contiguous neighborhood boundaries. In this context, homeowner upkeep effort would be conditioned by the distance toward upstream homeowners' effort provided in nearer neighborhoods. In short, we believe that our model's potential applications are broad enough to provide insight into a host of alternative policy settings.

Our findings emphasize the importance of effective institutional design and coordination mechanisms in addressing the challenges posed by spillovers. Moving forward, policymakers and practitioners can draw valuable insights from this research to inform the design of more robust and efficient environmental governance systems. It emphasizes the need for policy interventions that address the challenges posed by spillovers and jurisdictional fragmentation. What might an ideal or optimal institutional design of state regional offices look like in the context of water pollution control? The answer to this question depends upon whether watershed dissection occurs across state lines or across regional boundaries within a state. When watersheds are dissected by state boundaries, the obvious solution is greater attention by the U.S. EPA–the natural hierarchical actor to resolve state-level cooperation dilemmas. When watersheds are dissected by regional boundaries within the state, our results suggest that intra-state regional office boundaries would do better to follow watershed boundaries rather than county boundaries, the current norm. Regional offices with their watersheds when possible, states with lower the amount of dissected watersheds and enhance regional officers ownership over their resource. Another possibility, not pursued here but left to future work, is that state pollution control agencies may be able to mitigate intrastate cooperation problems by locating decision-making authority over enforcement activity at levels higher than the regional office. Such a nested hierarchical solution would incentivize a mid-level bureaucrat, with authority over competing regions, to intervene and resolve such cooperation dilemmas.

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A Proofs

It will take a few steps to prove Proposition 5. We begin with two useful results about the utility functions. First, for the regulators:

Lemma 11 (Regulator Utility is Convex)

Any $u_r \in \mathscr{U}_r$ *is continuous and quasiconcave in* e_r*.*

Proof. Choose and fix some e_{-r} and some c.

u_r *is continuous.* u_r is the composition of the map $a \mapsto \left((q_v(a))_{v\in J_r}, e_r\right) : A \to [0,1]^{\left|\rho^{-1}(r)\right|} \times [0,1]$, which is continuous by Assumption 2, and the map $(q,e) \mapsto \widetilde{u}_r(q,e) : [0,1]^{2|F|} \to \mathbb{R}$, which is continuous by Assumption 3. It therefore is itself continuous.

u_r *is quasiconcave in* e_r*.* Consider the map

$$e_r \overset{\psi}{\longmapsto} \left((q_v(e_r))_{v\in J_r}, -e_r\right) : [0,1] \longrightarrow [0,1]^{\left|\rho^{-1}(r)\right|} \times [-1,0]. \tag{6}$$

The first part of the output is quasiconcave thanks to Assumption 2. The second part is a monotone function of e_r, so it is also quasiconcave. As an increasing transformation of the quasiconcave function ψ, $\widetilde{u}_r$ is itself quasiconcave in e_r. ∎

And for facilities:

Lemma 12 (Facility Utility is Convex)

Any $u_f \in \mathscr{U}_f$ *is continuous and quasiconcave in* c_f*.*

Proof. Choose and fix some e and some c_{-f}.

u_f *is continuous.* u_f is the composition of the map $a \mapsto (c_f, -p_f(a))$, which is continuous by Assumption 1, and the map $(c,-p) \mapsto \widetilde{u}_f(c,-p)$, which is continuous by Assumption 4. It therefore is itself continuous.

u_f *is quasiconcave in* c_f. Consider the map

$$c_f \overset{\psi}{\longmapsto} (c_f, -p_f(c_f)) \,. \tag{7}$$

The first part is monotone and so is quasiconcave. By Assumption 1, the second part is also monotone in c_f, so it too is quasiconcave. As an increasing transformation of the quasiconcave function ψ, $\widetilde{u}_f$ is itself quasiconcave in c_f. ■

Our existence result is now immediate.

Proposition 5 (Equilibrium Existence)

Any regulatory game in the domain has at least one pure-strategy Nash equilibrium.

Proof. Each player's strategy set is the Euclidean compactum $[0, 1]$, and each player's utility function is continuous and quasiconcave in the relevant input (Lemmas 11 and 12). By the Debreu-Glicksberg-Fan theorem, the game has a pure-strategy Nash equilibrium. ■

We now turn our attention to the first vignette. As all three utility functions are differentiable in their relevant inputs, we can study the game's equilibria via the first-order conditions obtained from the usual Karush-Kuhn-Tucker (KKT) analysis. Since the utility functions are quasi-concave in their relevant inputs, we know that they are both necessary and sufficient for an equilibrium vector. We employ the Leibniz integral and product rules several times and endure tedious simplifying calculations to obtain the regulator's first-order conditions. To clarify exposition, define

$$\phi^{(1)} = c_A + e_A \left(1 - c_A\right)^2 \mu, \tag{8}$$

$$\phi^{(2)} = \eta_A \left(\phi^{(1)}, v_B\right) \times \left(c_B + e_B \left(1 - c_B\right)^2 \mu\right) . \tag{9}$$

Now we can write the regulator's first-order condition as

$$\zeta_R^{(A1)}(a;\theta) + \zeta_R^{(A2)}(a;\theta) + \zeta_R^{(A3)}(a;\theta) + \lambda_R^{(A1)}(a;\theta) - \lambda_R^{(A2)}(a;\theta) = 0, \tag{10}$$

$$\zeta_R^{(B1)}(a;\theta) + \zeta_R^{(B2)}(a;\theta) + \lambda_R^{(B1)}(a;\theta) - \lambda_R^{(B2)}(a;\theta) = 0, \tag{11}$$

where

$$\zeta_R^{(A1)}(a;\theta) = \mu\left(1 - c_A\right)^2 \int_0^{v_B} \frac{\partial \eta_A}{\partial \phi}\left(\phi^{(1)}, v\right) dv, \tag{12}$$

$$\zeta_R^{(A2)}(a;\theta) = \mu\left(1 - c_A\right)^2 \phi_B(a;\theta) \frac{\partial \eta_A}{\partial \phi}\left(\phi^{(1)}, v_B\right) \int_{v_B}^{1} \frac{\partial \eta_B}{\partial \phi}\left(\phi^{(2)}, v\right) dv, \tag{13}$$

$$\zeta_R^{(A3)}(a;\theta) = -\kappa e_A, \tag{14}$$

and

$$\zeta_R^{(B1)}(a;\theta) = \mu\left(1 - c_B\right)^2 \eta_A\left(\phi^{(1)}, v_B\right) \int_{v_B}^{1} \frac{\partial \eta_B}{\partial \phi}\left(\phi^{(2)}, v\right) dv, \tag{15}$$

$$\zeta_R^{(B2)}(a;\theta) = -\kappa e_B. \tag{16}$$

The KKT multiplers $\lambda_R^{(f\cdot)} \geqslant 0$ satisfy complementary slackness conditions

$$\lambda_R^{(f1)} e_f = 0, \tag{17}$$

$$\lambda_R^{(f2)}\left(1 - e_f\right) = 0. \tag{18}$$

As for the facilities, their first-order conditions take the form

$$2e_f\left(1 - c_f + \frac{\pi}{2}\right) + \lambda_f^{(f1)} - \lambda_f^{(f2)} = 1, \tag{19}$$

where again the KKT multipliers $\lambda_f^{(f\cdot)}$ satisfy complementary slackness conditions

$$\lambda_f^{(f1)} c_f = 0, \tag{20}$$

$$\lambda_f^{(f2)} (1 - c_f) = 0. \tag{21}$$

We arrive at Facility f's best response function

$$\widetilde{c}_f^*(a;\theta) = \begin{cases} 0, & e_f \leqslant \frac{1}{2+\pi}, \\ \frac{2e_f\left(1+\frac{\pi}{2}\right)-1}{2e_f}, & e_f \in \left[\frac{1}{2+\pi}, \frac{1}{\pi}\right] \\ 1, & e_f = \frac{1}{\pi} \end{cases} \tag{22}$$

Notice that e_f can only be equal to $\frac{1}{\pi}$ if $e_f = \pi = 1$. Further, at interior solutions, compliance is increasing in the regulator's relevant effort level and in the relevant punishment term.

Our three simplifying lemmas fall out of these first-order conditions. We first show that the facilities never comply perfectly.

Lemma 6 (Nobody's Perfect)

For both facilities $f \in F$, $c_f^* < 1$.

Proof. Suppose there existed an equilibrium featuring $c_A = 1$. Then $(1 - c_A)^2 = 0$, meaning $\zeta_R^{(A1)}(a;\theta) = \zeta_R^{(A2)}(a;\theta) = 0$, which sets the regulator's first condition to

$$-\kappa e_A + \lambda_R^{(A1)} - \lambda_R^{(A2)} = 0.$$

If $e_A = 0$, then $\lambda_R^{(A1)} \geqslant 0$ is allowed to fluctuate but $\lambda_R^{(A2)} = 0$ by complementary slackness. Set $\lambda_R^{(A1)} = 0$ (encoding the lack of marginal benefit in inspecting perfectly-compliant facilities) and the condition is satisfied. If $e_A \in (0, 1)$, then the two multipliers disappear by complementary slackness, and the first condition is $-\kappa e_A = 0$. This cannot hold. The same goes if $e_A = 1$: the first multiplier disappears, setting the condition to $-\kappa - \lambda_R^{(A2)} = 0$, which never holds.

We just showed that if $c_A = 1$ in any equilibrium, then e_A must be equal to 0. But since the best response to $e_A = 0$ is $\widetilde{c}_A^* = 0$, we have arrived at a contradiction.

The argument for c_B is identical save for the fact that $(1 - c_B)^2$ sets $\zeta_R^{(B1)} = 0$ by itself, as the marginal benefit of inspecting B arrives in but a single integral-oriented chunk rather than a pair of integral-oriented chunks. [*Back to the text.*] ∎

The second lemma shows that the inspector is vigilant save for a limiting case at the bottom.

Lemma 7 (Vigilance Save for the Bottom)

$e_A^* > 0$ *and* $(e_B^* > 0 \iff v_B < 1)$.

Proof. By Lemma 6, we know that $c_f^* > 0$ for both f. Then $(1 - c_A^*)^2 > 0$, ensuring

$$\underbrace{\zeta_R^{(A1)}(a;\theta)}_{>0} + \underbrace{\zeta_R^{(A2)}(a;\theta)}_{\geqslant 0} > 0. \tag{23}$$

This holds because $\mu > 0$ by assumption and $\frac{\partial \eta_f}{\partial \phi}(\phi, v)$ is strictly positive by construction, making its integral across any nontrivial interval of V strictly positive, too. If $e_A = 0$ were part of an equilibrium, then it would necessarily abide

$$\underbrace{\zeta_R^{(A1)}(a;\theta) + \zeta_R^{(A2)}(a;\theta)}_{>0} + \underbrace{\lambda_R^{(A2)}}_{\geqslant 0} = 0, \tag{24}$$

since $\zeta_R^{(A3)} = 0$ because $e_A = 0$ and $\lambda_R^{(A2)} = 0$ by complementary slackness. This condition cannot be satisfied; we conclude that $e_A^* > 0$.

Now suppose $e_B > 0$ were part of an equilibrium. It therefore satisfies

$$\underbrace{\zeta_R^{(B1)}(a;\theta)}_{\geqslant 0} - \underbrace{\kappa e_B - \lambda_R^{(B2)}}_{<0} = 0. \tag{25}$$

This can hold only if $\zeta_R^{(B1)}(a;\theta) > 0$, which requires $v_B < 1$—otherwise we would be integrating over a single point, rendering $\zeta_R^{(B1)}(a;\theta) = 0$.

Finally, suppose $v_B = 1$. Then $\zeta_R^{(B1)}(a;\theta) = 0$, as the integral goes to zero. The regulator's second condition is therefore

$$-\kappa e_A + \lambda_R^{(B1)} - \lambda_R^{(B2)} = 0. \tag{26}$$

This holds only if $e_A = \lambda_R^{(B1)} = 0$. [*Back to the text.*] ∎

Our final simplifying lemma relates zero effort to zero compliance; this is immediate from our derivation of $\widetilde{c}_f^*$.

Lemma 8 (When the Cat's Away)

For both $f \in F$, $e_f^* = 0 \implies c_f^* = 0$.

Proof. Let $e_f = 0$ for either $f \in F$. Then $\widetilde{c}_f^* = 0$, too. [*Back to the text.*] ∎

With these lemmas in place, we can now show that effort and compliance vanish as the downstream facility grows closer to the drain point.

Proposition 9 (Convergence to the Bottom)

Let $\left(\theta^{(m)}\right) \in \Theta^\infty$ be a parameter sequence that converges to some $\overline{\theta} \in \Theta$ featuring $v_B = 1$. Then for any $\varepsilon > 0$, there exists some $\overline{m} \in \mathbb{N}$ such that

$$\overline{m} \leqslant m \implies \max\left\{e_B^*\left(\theta^{(m)}\right), c_B^*\left(\theta^{(m)}\right)\right\} < \varepsilon.$$

Proof. We introduce the equilibrium correspondence $E^* : \Theta \rightrightarrows A$, where

$$E^*(\theta) = \{a \in A \mid a \text{ is a pure-strategy Nash equilibrium for } \Gamma(\theta)\}. \tag{27}$$

It is well-known that E^* is upper hemicontinuous. Let $\left(\theta^{(m)}\right)$ be a parameter sequence as described in the claim, and let $\left(a^{(m)}\right) \in A^\infty$ be a sequence of strategy profiles such that

$a^{(m)} \in E^* \left(\theta^{(m)}\right)$ for all $m \in \mathbb{N}$. Observe that Lemmas 7 and 8 tell us that any $a \in E^* \left(\overline{\theta}\right)$ must feature $e_B^* = c_B^* = 0$. Since A is compact, the sequential characterization of upper hemicontinuity delivers the desired result. ■

B Regression Tables

Table S3. Estimates for Area and Upstream on Sampling Inspections

	Sampling Inspections		
	(Area=1.0)	(Area>.95)	(Area>.90)
Area	−0.032	−0.020	−0.061*
	(0.0286)	(0.0301)	(0.0342)
Upstream	−0.055**	−0.047*	−0.080***
	(0.0245)	(0.0253)	(0.0275)
Area × Upstream	0.081**	0.061*	0.142***
	(0.0340)	(0.0371)	(0.0444)
Facility Age	0.002***	0.0018***	0.0017***
	(0.0004)	(0.0004)	(0.0004)
Publicly Owned Treatment Works	0.0523***	0.0452***	0.0503***
	(0.0107)	(0.0116)	(0.0130)
Utility Facility	−0.0218	−0.0283*	−0.0234
	(0.0158)	(0.0167)	(0.0182)
Utility Facility	0.0261*	0.0278*	0.0346**
	(0.0139)	(0.0151)	(0.0168)
Percent Black	0.125***	0.083***	0.118***
	(0.0304)	(0.0294)	(0.0320)
Percent Hispanic	0.122***	0.141***	0.159***
	(0.0426)	(0.0463)	(0.0485)
Percent College Education	−0.0400	−0.029	−0.120
	(0.0689)	(0.0764)	(0.0743)
Percent Poverty	0.0401	0.114	−0.0287
	(0.0755)	(0.0793)	(0.0812)
Percent Home Owners	0.0705**	0.0963***	0.103**
	(0.0354)	(0.0368)	(0.0428)
Percent High School Education	0.0795	0.0360	0.0981
	(0.0619)	(0.0641)	(0.0683)
Median Household Income per 1000	0.0011**	0.0010**	0.0011**
	(0.0005)	(0.0005)	(0.0005)
Reportable Noncompliance	−0.0037	−0.0059	−0.0093
	(0.0072)	(0.0078)	(0.0089)
Significant Noncompliance	−0.0007	−0.0073	−0.0052
	(0.0070)	(0.0072)	(0.0081)
Total Facilities per 1000 (Regional Office)	−0.0047*	−0.0052*	−0.0050
	(0.0028)	(0.0029)	(0.0031)
Total Major Facilities (Regional Office)	−0.0010***	−0.0010***	−0.0009***
	(0.0001)	(0.0001)	(0.0001)
Unemployment Rate	0.0368***	0.0336***	0.0322***
	(0.0060)	(0.0064)	(0.0067)
State GSP per 1000	0.0001***	0.0001***	0.0000**
	(< 0.0001)	(< 0.0001)	(< 0.0001)
Democratic Governor	−0.0828***	−0.0903***	−0.110***
	(0.0122)	(0.0126)	(0.0136)
Percent Democrats (State House)	0.756***	0.747***	0.764***
	(0.0609)	(0.0653)	(0.0695)
Bush Administration	0.174***	0.167***	0.180***
	(0.0138)	(0.0146)	(0.0152)
Unified Republican Congress	−0.0784***	−0.0804***	−0.0767***
	(0.0249)	(0.0272)	(0.0293)
Total Majors(Watershed)	−0.0023***	−0.0021***	−0.0009
	(0.0005)	(0.0005)	(0.0006)
Total Facilities per 1000(Watershed)	−0.0085	−0.0089	−0.0150**
	(0.0069)	(0.0071)	(0.0075)
EPA Region Dummies	—	—	—
	—	—	—
Year Dummies	—	—	—
	—	—	—
Constant	−0.510***	−0.466***	−0.465***
	(0.0788)	(0.0767)	(0.0799)
ρ (intraclass correlation)	0.151	0.156	0.155
Groups	3701	3242	2651
Observations	48095	42128	34445

Note: Coefficients are estimates from a linear random-effects GLS regression with robust standard errors in parentheses. EPA region and year dummies not displayed. Two-tailed tests. Statistical significance: ***$p < .01$, **$p < .05$, *$p < .10$.

Table S4. Estimates for Area and Upstream on NonSampling Inspections

	NonSampling Inspections		
	(Area=1.0)	(Area>.95)	(Area>.90)
Area	−0.229*	−0.156	−0.318**
	(0.129)	(0.135)	(0.152)
Upstream	0.0677	0.0363	−0.120
	(0.116)	(0.118)	(0.122)
Area × Upstream	0.0034	0.0524	0.379**
	(0.158)	(0.165)	(0.189)
Facility Age	0.0121***	0.0117***	0.0103***
	(0.0018)	(0.0019)	(0.0022)
Publicly Owned Treatment Works	0.306***	0.378***	0.416***
	(0.0581)	(0.0623)	(0.0711)
Utility Facility	−0.340***	−0.290***	−0.220**
	(0.0732)	(0.0776)	(0.0856)
Utility Facility	−0.161**	−0.0950	−0.0154
	(0.0700)	(0.0762)	(0.0842)
Percent Black	0.572***	0.537***	0.553***
	(0.148)	(0.156)	(0.172)
Percent Hispanic	−0.455**	−0.307	0.240
	(0.231)	(0.277)	(0.313)
Percent College Education	0.325	0.256	0.518
	(0.348)	(0.389)	(0.456)
Percent Poverty	−1.158***	−1.351***	−1.591***
	(0.371)	(0.407)	(0.439)
Percent Hone Owners	−0.658***	−0.658***	−0.752***
	(0.209)	(0.230)	(0.273)
Percent High School Education	−1.297***	−1.429***	−0.952***
	(0.270)	(0.299)	(0.336)
Median Household Income per 1000	0.0007	0.0002	−0.0005
	(0.0022)	(0.0024)	(0.0027)
Reportable Noncompliance	−0.0837***	−0.0989***	−0.0737***
	(0.0223)	(0.0248)	(0.0284)
Significant Noncompliance	0.0161	0.0183	0.0426
	(0.0262)	(0.0292)	(0.0341)
Total Facilities per 1000 (Regional Office)	−0.0054	−0.0035	0.0125
	(0.0154)	(0.0166)	(0.0185)
Total Major Facilities (Regional Office)	−0.0023***	−0.0024***	−0.0027***
	(0.0004)	(0.0005)	(0.0006)
Unemployment Rate	0.219***	0.250***	0.261***
	(0.0294)	(0.0301)	(0.0310)
State GSP per 1000	0.0003***	0.0003***	0.0002***
	(0.0001)	(0.0001)	(0.0001)
Democratic Governor	0.290***	0.230***	0.0920
	(0.0541)	(0.0564)	(0.0619)
Percent Democrats (State House)	3.52***	3.57***	3.57***
	(0.300)	(0.302)	(0.319)
Bush Administration	0.751***	0.773***	0.826***
	(0.0506)	(0.0558)	(0.0631)
Unified Republican Congress	−0.635***	−0.692***	−0.534***
	(0.104)	(0.115)	(0.130)
Total Majors(Watershed)	−0.0032	−0.0028	−0.0052**
	(0.0020)	(0.0021)	(0.0026)
Total Facilities per 1000(Watershed)	0.0700**	0.0682**	0.0452
	(0.0299)	(0.0312)	(0.0358)
EPA Region Dummies	—	—	—
	—	—	—
Year Dummies	—	—	—
	—	—	—
Constant	−1.51***	−1.75***	−1.86***
	(0.365)	(0.390)	(0.430)
ρ (intraclass correlation)	0.336	0.328	0.315
Groups	3701	3242	2651
Observations	48095	42128	34445

Note: Coefficients are estimates from a linear random-effects GLS regression with robust standard errors in parentheses. EPA region and year dummies not displayed. Two-tailed tests. Statistical significance: $^{***}p < .01$, $^{**}p < .05$, $^{*}p < .10$.

Table S5. Estimates for Area and Nearest Downstream Border on Sampling Inspections

	Sampling Inspections		
	(Area=1.0)	(Area>.95)	(Area>.90)
Area	−0.0849**	−0.0601	−0.0129
	(0.0377)	(0.0415)	(0.0506)
Downstream Border Distance	−0.0048***	−0.0044***	−0.0037**
	(0.0015)	(0.0015)	(0.0017)
Area × Downstream Border Distance	0.0062***	0.0053**	0.0035
	(0.0019)	(0.0021)	(0.0025)
Facility Age	0.0019***	0.0017***	0.0017***
	(0.0004)	(0.0004)	(0.0004)
Publicly Owned Treatment Works	0.0440***	0.0361***	0.0391**
	(0.0123)	(0.0136)	(0.0153)
Utility Facility	−0.0183	−0.0241	−0.0206
	(0.0168)	(0.0180)	(0.0198)
Utility Facility	0.0331**	0.0371**	0.0409**
	(0.0162)	(0.0177)	(0.0199)
Percent Black	0.138***	0.104***	0.140***
	(0.0318)	(0.0314)	(0.0344)
Percent Hispanic	0.153***	0.207***	0.236***
	(0.0448)	(0.0507)	(0.0540)
Percent College Education	−0.0582	−0.0708	−0.179**
	(0.0688)	(0.0750)	(0.0746)
Percent Poverty	0.0572	0.121	0.0230
	(0.0773)	(0.0816)	(0.0870)
Percent Hone Owners	0.0464	0.0655	0.0679
	(0.0389)	(0.0417)	(0.0484)
Percent High School Education	0.143**	0.113*	0.176**
	(0.0648)	(0.0666)	(0.0713)
Median Household Income per 1000	0.0013***	0.0013***	0.0017***
	(0.0005)	(0.0005)	(0.0005)
Reportable Noncompliance	0.0003	−0.0015	−0.0025
	(0.0078)	(0.0084)	(0.0095)
Significant Noncompliance	−0.0036	−0.0083	−0.0074
	(0.0071)	(0.0073)	(0.0080)
Total Facilities per 1000 (Regional Office)	−0.0068**	−0.0080**	−0.0074*
	(0.0033)	(0.0035)	(0.0040)
Total Major Facilities (Regional Office)	−0.0008***	−0.0008***	−0.0009***
	(0.0001)	(0.0001)	(0.0002)
Unemployment Rate	0.0361***	0.0347***	0.0336***
	(0.0062)	(0.0064)	(0.0068)
State GSP per 1000	0.0001***	0.0001***	0.0000**
	(<0.0001)	(<0.0001)	(<0.0001)
Democratic Governor	−0.0732***	−0.0804***	−0.0899***
	(0.0121)	(0.0124)	(0.0136)
Percent Democrats (State House)	0.854***	0.848***	0.861***
	(0.0677)	(0.0709)	(0.0747)
Bush Administration	0.187***	0.180***	0.196***
	(0.0138)	(0.0146)	(0.0150)
Unified Republican Congress	−0.0704***	−0.0694**	−0.0694**
	(0.0253)	(0.0273)	(0.0292)
Total Majors(Watershed)	−0.0031***	−0.0030***	−0.0018***
	(0.0005)	(0.0005)	(0.0006)
Total Facilities per 1000(Watershed)	0.0072	0.0088	0.0075
	(0.0106)	(0.0113)	(0.0131)
EPA Region Dummies	—	—	—
	—	—	—
Year Dummies	—	—	—
	—	—	—
Constant	−0.516***	−0.498***	−0.554***
	(0.0822)	(0.0810)	(0.0879)
ρ (intraclass correlation)	0.163	0.171	0.173
Groups	3891	3460	2955
Observations	50565	44962	38397

Note: Coefficients are estimates from a linear random-effects GLS regression with robust standard errors in parentheses. EPA region and year dummies not displayed. Two-tailed tests. Statistical significance: ***$p < .01$, **$p < .05$, *$p < .10$.

Table S6. Estimates for Area and Nearest Downstream Border on NonSampling Inspections

	NonSampling Inspections		
	(Area=1.0)	(Area>.95)	(Area>.90)
Area	−0.622***	−0.507***	−0.605***
	(0.154)	(0.174)	(0.212)
Downstream Border Distance	−0.0293***	−0.0303***	−0.0317***
	(0.0057)	(0.0059)	(0.0063)
Area × Downstream Border Distance	0.0364***	0.0365***	0.0402***
	(0.0077)	(0.0086)	(0.0102)
Facility Age	0.0112***	0.0108***	0.0092***
	(0.0022)	(0.0025)	(0.0027)
Publicly Owned Treatment Works	0.312***	0.358***	0.396***
	(0.0572)	(0.0635)	(0.0715)
Utility Facility	−0.385***	−0.360***	−0.285***
	(0.0700)	(0.0760)	(0.0834)
Utility Facility	−0.122	−0.0900	−0.0157
	(0.0856)	(0.0939)	(0.1056)
Percent Black	0.538***	0.494***	0.524***
	(0.143)	(0.148)	(0.163)
Percent Hispanic	−0.583***	−0.443*	0.0745
	(0.221)	(0.264)	(0.292)
Percent College Education	0.0511	−0.0759	0.0686
	(0.354)	(0.392)	(0.458)
Percent Poverty	−1.06***	−1.17***	−1.32***
	(0.363)	(0.400)	(0.430)
Percent Hone Owners	−0.758***	−0.662***	−0.742***
	(0.209)	(0.223)	(0.260)
Percent High School Education	−0.987***	−1.122***	−0.629**
	(0.256)	(0.280)	(0.303)
Median Household Income per 1000	0.0025	0.0015	0.0015
	(0.0024)	(0.0025)	(0.0028)
Reportable Noncompliance	−0.0789***	−0.0895***	−0.0696**
	(0.0229)	(0.0253)	(0.0281)
Significant Noncompliance	0.0202	0.0267	0.0472
	(0.0261)	(0.0289)	(0.0326)
Total Facilities per 1000 (Regional Office)	−0.0588***	−0.0621***	−0.0625***
	(0.0134)	(0.0146)	(0.0159)
Total Major Facilities (Regional Office)	−0.0015***	−0.0014***	−0.0013**
	(0.0004)	(0.0005)	(0.0006)
Unemployment Rate	0.214***	0.233***	0.238***
	(0.0271)	(0.0278)	(0.0281)
State GSP per 1000	0.0002***	0.0002**	0.0001
	(0.0001)	(0.0001)	(0.0001)
Democratic Governor	0.379***	0.331***	0.277***
	(0.0538)	(0.0562)	(0.0602)
Percent Democrats (State House)	3.678***	3.74***	3.60***
	(0.309)	(0.322)	(0.334)
Bush Administration	0.805***	0.815***	0.863***
	(0.0509)	(0.0545)	(0.0597)
Unified Republican Congress	−0.546***	−0.609***	−0.455***
	(0.0964)	(0.106)	(0.113)
Total Majors(Watershed)	−0.0047**	−0.0045**	−0.0089***
	(0.0020)	(0.0021)	(0.0025)
Total Facilities per 1000(Watershed)	0.127***	0.140***	0.178***
	(0.0370)	(0.0392)	(0.0461)
EPA Region Dummies	—	—	—
	—	—	—
Year Dummies	—	—	—
	—	—	—
Constant	−1.19***	−1.36***	−1.45***
	(0.358)	(0.379)	(0.417)
Groups	3891	3460	2955
Observations	50565	44962	38397

Note: Coefficients are estimates from a linear random-effects GLS regression with robust standard errors in parentheses. EPA region and year dummies not displayed. Two-tailed tests. Statistical significance: $^{***}p < .01$, $^{**}p < .05$, $^{*}p < .10$.