(Chapter 3) The Allocation of Environmental Monitoring Resources: Prelude to an Empirical Test[1]

Sanford Gordon
Department of Political Science
The Ohio State University
gordon.256@osu.edu

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1 Introduction

In debates over the proper locus of government authority in the United States, much of the conversation has focused on environmental policy making and implementation. Advocates of local control of environmental policy have pointed to potential efficiency gains associated with devolution (Butler and Macey 1996; Revesz 1997). Environmental regulation is enormously complex, and state regulators are in a better position to develop expertise about jurisdiction-specific problems. At the same time, states differ in their demand for regulation. Some populations may be willing to sacrifice some economic growth for a cleaner or safer environment, while others might trade in the opposite direction. Devolution allows states to calibrate their environmental policies to conflicting demands through the political process.

Critics of devolution, who favor a greater federal role, counter that state officials have little incentive to internalize pollution costs borne by the citizens of other states. Further, some officials in some states might be ideologically opposed to environmental regulation, and do their best to thwart it. Still others might feel compelled to attract or retain industry by reducing the regulatory burden (Cumberland 1981; McConnell and Schwab 1990; Kuehn 1996; Bartik 1988). This dynamic might lead to a "race to the bottom" where all states regulate insufficiently. In general, the structural position of states in a federal system makes the decentralized provision of adequate environmental regulation a dubious enterprise at best.

Another additional concern with devolution concerns not the creation of environmental policy, but the enforcement of existing federal rules. State environmental officials, according to this view, are more easily manipulated or captured by powerful local interests than the federal EPA is. Federal bureaucrats and environmental activists frequently voice this apprehension. Consider the comments of Erik D. Olson, a senior attorney at the National Resources Defense Counsel, at a forum on environmental federalism in February, 2001. Olson observes, "There is just enormous industry power at the state and local level," and continues,

> There is the lack of funding staff and expertise at many states. Very often, even if they have the political will, which is another huge obstacle, the states simply cannot take

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> on a major industry. The industry can throw enormous resources and essentially wear the state down to the point where a twenty-four year old kid straight out of school who is tasked with fighting the thirty industry lawyers simply cannot muster the attention and will to take them on (Markell et. al. 2001, pp. 1102, 1124).

This pessimistic appraisal of state environmental policy implementation has its roots in Madison's famous critique of small republics in the *Federalist* #10. Both suggest a "mischief of faction" adverse to the general welfare that predominates in state and local politics. The solution to this problem for critics of devolution, as it was for Madison, is the creation and maintenance of strong national institutions. The problem of local industry power, Olson argues, "really cannot be dealt with unless there is a major federal presence."

Empirical analyses seeking to document either partisan bias in state environmental policy implementation or favoritism toward powerful local industries have had mixed results (List and Gerking 2000; Williams and Matheny 1984; Lester, Franke, Bowman, and Kramer 1983; Wood 1992). The less-than-overwhelming record of the empirical studies of environmental federalism, I believe, may be attributed to two fundamental difficulties. One of these is methodological. Often, empirical models of environmental enforcement fail to account sufficiently for the complexity of the regulatory task, interregional environmental differences, and the strategic nature of regulatory interactions. For example, a finding that there is little capital mobility in search of lax environmental standards (McConnell and Schwab 1990; Bartik 1988) could be interpreted as evidence not of the absence of a motive for a "race to the bottom," but rather of the total capitulation of state actors to the demands of mobile capital. Likewise, a finding of reduced enforcement intensity under certain political regimes can imply either a reduction in the enforcement efforts of regulators or an increase in the compliance efforts of regulated parties. The supply of infractions, in other words, is not static, so the fact of reduced enforcement does not by itself permit us to distinguish between the two explanations.

Another problem, which relates to the broader themes of this book, is a failure to account adequately for the incentives of the bureaucrats implementing regulatory policy. Political principals and interest groups may endeavor to influence the behavior of regulators, but their ability to

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do so will be constrained by a number of intervening factors. The first is asymmetric information: Elected officials and agency administrators experience difficulty trying to observe the performance of their subordinates. This may foster an emphasis on rewarding easily observable outputs instead of outcomes (Wilson 1989). In the context of regulatory monitoring, asymmetric information reinforces an already latent preference most professional bureaucrats have toward maximizing the detection of violations, and not necessarily minimizing their occurrence. The second is that environmental bureaucracies are serve multiple principals (Dixit 1997; Dixit, Grossman, and Helpman 1997; Bernheim and Whinston 1986): The multiplicity of superiors with conflicting demands mitigates their ability to coordinate efforts to alter agency activity, and can distort or weaken agents' incentives.

The third problem, which is particularly important in the context of environmental regulation, is resource autonomy. The vast majority of environmental monitoring and enforcement in the United States operates under a system of "partial preemption" (Hedge and Scicchitano 1993), in which the federal government establishes minimum national standards and then authorizes state regulators to implement and enforce them. Many state programs are funded in large part by categorical grants made by the federal EPA. If a state agency is not dependent on its legislature for its resources, then legislators will be frustrated in their efforts to induce agency compliance with their preferences.

The Resource Conservation and Recovery Act of 1976 (RCRA), which establishes a framework for regulating the generation, treatment, and disposal of hazardous waste in the United States, is one such partial preemption program. The monitoring behavior of state environmental agencies pursuant to RCRA provides an ideal setting to examine existing theories of enforcement politics in the context of environmental federalism, as well as their limitations. In terms of government resources allocated and estimated aggregate compliance costs, hazardous waste regulation is the third largest national environmental program in the United States. Unlike the externalities associated with Clean Air and Clean Water regulations, those associated with the generation of hazardous waste (though not necessarily its disposal) are usually proximate to their sources. Thus, we can

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reasonably focus our attention on the intrastate politics of hazardous waste enforcement, whereas in the case of air and water we must be concerned with ubiquitous cross-border conflicts.

I begin this chapter with a general discussion of the objectives regulators pursue when they allocate their monitoring resources across the universe of regulated facilities in their jurisdiction. Then, after discussing the complexity of hazardous waste regulation in detail, and how this complexity contributes to methodological difficulties in ascribing political motivations to state-level bureaucrats, I develop a formal model of monitoring allocation. Firms in the model differ both in terms of their technical characteristics and their ability to threaten political costs to the regulator. The regulator must decide how to disburse her finite monitoring resources in light of these costs. The firms, in turn, decide whether and how much to invest in regulatory compliance.

Due to its complexity, the model has no closed-form solution in which strategies can be expressed as functions of primitive preferences and firm and agency characteristics. In other words, it is impossible in the current setting directly to express the intensity of monitoring at a particular facility as a function of a firm's political or technical attributes. However, the model does suggest a set of conditions that must hold if the regulator's monitoring allocation strategy is in equilibrium with the compliance strategies of the firms. The most important prediction is that if all firms were identical in terms of their technological and political characteristics, a regulator seeking to maximize the number of detected violations would target her monitoring resources to equalize the marginal expected return from inspection across all facilities. If inspecting Facility A is more costly than inspecting Facility B (whether for political or technical reasons), then in equilibrium, an additional dollar spent monitoring A will uncover more, and more severe, violations than one spent at B. This implies that firms that can impose high political costs on a regulator will be under-deterred, even if they are inspected at equal or even higher frequencies than their counterparts. The prediction is similar to ones offered in economic models of racial discrimination (e.g. Ayres and Waldfogel 1994; Knowles, Persico, and Todd 2001). The relationship between regulatory return and the political cost of inspection, and how an agency's institutional position can serve to weaken regulators' incentives to discriminate among different firms, is at the heart of the empirical analysis

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in the next chapter.

2 Strategies for Hazardous Waste Monitoring

2.1 Equity, Detection, or Deterrence?

Regulatory agencies can alter their monitoring strategies by changing the aggregate intensity of inspection efforts or varying the allocation of resources across the universe of regulated entities. To change the aggregate intensity, regulators may endeavor to alter the total resource level allocated to monitoring. In the United States, any effort to alter the budget must pass a number of procedural hurdles within the executive branch before being submitted for approval by the legislature. In the case of federal programs with state-level implementation, changing the allotment of monitoring resources must also be approved by the delegating federal agency. Other difficulties with altering resources allocated to monitoring stem from bureaucratic inertia: Staff hired to conduct inspection activity cannot be easily reassigned or retrained should their services no longer be required. Finally, regulators can change the monitoring technology in an attempt to make detection easier to accomplish. In recent years, for example, state-level implementation of the Clean Water Act has witnessed a dramatic change in technology. Agents assessing compliance now rely as much on computer printouts sent to them by permittees as on field inspections.

A regulator has far more discretion in allocating monitoring resources than in altering their overall intensity. To what ends might she use this discretion? First, the agent might be motivated by concerns about equity or procedural consistency. This objective requires that each regulated entity be subjected to the same ex ante probability and intensity of monitoring. In other words, who is monitored at any given time should be governed by a purely random audit policy. Monitoring intensity under random audits would be independent of the regulator's beliefs about a party's past behavior, its ability to comply, its importance, or any other criterion employed to differentiate among parties. This conception of equity seems naive at first glance, in that it asks the regulator to

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forego her expertise entirely when allocating resources.

The value of procedural equity in monitoring emerges from the fact that monitoring is costly not only to the regulator, but also to the party subjected to investigation (Persico 2001). Costs to the scrutinized individual might include humiliation, delay, diversion of employees, and lost business. Even if regulators are not concerned about these costs, they might take equity concerns into account when targeting for two reasons. First, regulated parties can complain to their elected representatives that they were singled out for unfair treatment. Grievances of this sort led to major restructuring and painful budget cuts for the IRS in 1998. Second, respondents to enforcement actions by a regulatory agency sometimes accuse it of selective enforcement. Demonstrating the underlying equity of a targeting strategy can overcome legal hurdles to the agency. Finally, random audits allow regulators to gauge overall compliance rates (U.S. EPA 1996, 7).

The second goal a regulator will consider is maximizing the number of detected violations. A drive to detect and correct existing violations is at the core of an inspector's professional norms. Also, well-publicized violations can increase the visibility of the agency's activities, resulting in public pressure on elected officials to increase the resources available to the agency. Further, political and administrative superordinates may reward or punish an agency on the basis of its success in detection. Interestingly, if the urge to uncover existing violations is induced by the regulator's position as an agent, it will likely be independent of the political preferences of the relevant principal. This point was brought home in informal interviews I conducted with EPA personnel. When Democrats controlled Congress, one manager noted, the EPA felt pressure to detect violations because congressional leaders felt that a strong, visible agency presence in business affairs would compel polluting industries to comply more readily. When the Republicans took over Congress in 1994, this pressure did not abate. EPA enforcement personnel still had a strong incentive to detect violations, in order to demonstrate that noncompliance was a ubiquitous problem necessitating continued strong budgetary support of the agency. In general, the detection goal will be in tension with the goal of equity, because some regulated parties are either more dangerous or more likely to violate than others are. A detection-oriented regulator will depart from an unconditionally

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equitable strategy, allocating more of her monitoring resources to the firms or individuals that she believes are either more hazardous or more likely to generate violations.

Detection is likely to dominate consistency and a third goal, deterrence, as the regulator's maximand. A regulator's primitive preference may be to minimize the number of violations that occur (as distinguished from the number of violations detected). Insofar as the mission of a regulatory agency is to prevent externality-causing behavior, a deterrence-based strategy is more efficient than a detection- or consistency-based one. The chief problem with such an approach, however, is that it is nearly impossible to evaluate. In most cases, information regarding compliance comes from the agency doing the monitoring and enforcement. From the perspective of a manager or political principal, a perfectly successful deterrence-based monitoring scheme is, absent an external measure of performance, observationally equivalent to an incompetent detection-based monitoring scheme.[1] This is especially true in the field of environmental enforcement, where the adverse effects of undetected violations may manifest themselves in health effects felt years or even decades after the infraction.

Further, a principal that desires a deterrence-based approach will nonetheless expect that not all regulated parties will be successfully deterred – either because the opportunity cost of compliance is too large or the agency's resources are too small. In those cases, a small number of detected violations still appears as a failure by the agency even if the regulator diligently targets for deterrence. As in many principal-agent relationships in which the agent is responsible for multiple tasks (Holmstrom and Milgrom 1991), the fact that one of these tasks is relatively easy to measure will induce the agent to try to maximize output along that dimension.[2]

[1]This equivalence leads to some amusing cheap talk by the EPA in its annual enforcement reports. When the number of detected violations declines, regulators will argue the drop resulted from effective deterrence. When it increases, they will claim it emerged from diligent intervention.

[2]This regularity is not only true for environmental agencies. State highway patrol officers, for example, are informally rewarded within their organizations for successful drug detection during roadside searches (Knowles, Persico, and Todd 2001). An unstructured interview with a compliance officer from the Food and Drug Administration revealed similar behavior. That agent suggested that detection was the *only* thing regulators cared about.

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2.2 The Underlying Complexity of Hazardous Waste Regulation

Subtitle C of the Resource Conservation and Recovery Act of 1976 (RCRA), its 1984 amendments, and its accompanying regulations (40 C.F.R. 61) provide the ground rules for the regulation of active hazardous waste generators, transporters, and treatment, storage, and disposal facilities in the United States.[3] The program is enormous in its scope and comprehensiveness, providing for the handling of all non-household hazardous waste from "cradle to grave." The EPA is responsible for characterizing waste products as hazardous according to their toxicity, ignitability, corrosivity, and reactivity, developing minimum national standards for the management of these products, and overseeing the state agencies authorized to implement the program. Over the 25 years since the passage of RCRA, the EPA has gradually delegated primary monitoring and enforcement authority to the states (Staudinger 1996). State agencies vary considerably in the degree to which they share implementation duties with the EPA. In 2000, for example, Alaska, Hawaii, and Iowa had no state programs; the EPA alone handled regulation in those states. By contrast, Delaware was authorized to implement over 90% of federal hazardous waste rules. The median state that year, Wisconsin, had about 60% authorization.[4]

Per RCRA and its accompanying regulations, a facility or plant is considered a "large quantity generator" (LQG) of hazardous waste if it produces more than 1,000 kilograms of normal hazardous waste or one kilogram of acute hazardous waste per calendar month. Currently, there are about 20,000 such facilities in the United States. Regulations governing these plants concern labeling and measurement of waste products, containment, preparation of wastes for transportation, shipment tracking, and record keeping. LQGs also develop emergency response plans and training programs for personnel charged with handling waste, and are expected to adhere to detailed management requirements.

In 1999, the state of New Jersey had 1,071 LQG facilities within its borders, ranking fourth

[3]The legislation governing the regulation and cleanup of inactive or abandoned hazardous waste sites is the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, more commonly known as Superfund, after the trust fund that the statute created.

[4]Figures are derived from U.S. EPA, State Authorization Tracking System (STATS).

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nationwide behind New York, California, and Ohio. Through most of the 1990s, its Department of Environmental Protection (DEP) had authorization to administer roughly ten percent of all federal hazardous waste rules. The DEP's monitoring activity at two LQG facilities under its jurisdiction during this time period provides a snapshot of the complexity of the regulatory task.

Dri-Print Foils. The first facility, Dri-Print, is located in Rahway just east of New Jersey Transit's Northeast Corridor railway line. Rahway is located in Union County, in population terms, the third densest in the state. A division of the API Group, a British conglomerate, Dri-Print generates metal foil, leaf, and laminate material. This is the metallic substance that appears on wrapping paper, stationery, packaging material, greeting cards, labels, and the lettering of cloth-bound book covers. Dri-Print also makes the holographic film that appears on identity and credit cards. Between 1990 and 1997, the facility generated about 821 tons of hazardous waste, mostly assorted spent solvents. In the 1980s, state and federal officials detected three violations at the plant. Despite this, from 1990 to 1997, neither EPA nor DEP ever inspected the site.

Dupont Deepwater Site. The second facility is the Dupont Elastomers Chambers Dye Works in Deepwater, NJ. Located north of the Delaware Memorial Bridge in Salem County, the most sparsely populated in the state, Dupont's 700-acre chemical manufacturing campus has a long history of both technological advance and environmental notoriety. Built in the waning days of World War I to challenge the German monopoly on dye manufacturing (Hounshell and Smith 1988), the facility housed the laboratory in which Dupont scientists developed the technique for refining uranium into fissionable material for the Hiroshima atomic bomb. In the 1950s and 1960s, popular consumer chemicals such as Neoprene and Teflon were developed at Deepwater. Today, the amount of hazardous waste produced at the Deepwater facility is stunning: From 1990 to 1997, the Chambers Works produced close to 150 million tons of waste, making the site the sixth largest generator in the country for that period.[5] The list of differentiated waste products generated in 1997 alone runs 227 pages.

In the 1980s, regulators detected 42 violations at the Deepwater plant. Their continued in-

[5]The largest was Franklin Paper in Jay, ME.

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spection efforts in the early 1990s uncovered 59 more. EPA records suggest 71 separate inspections of the Dye Works site from 1990 to 1997. A better measure of the intensity of monitoring at Deepwater, however, emerges when one observes the number of evaluation "areas," various categories of inspection that can serve as a proxy of the thoroughness of a single visit to a facility. Specific evaluation areas include general requirements for generators, record-keeping requirements, or manifest regulations (all waste products must be accompanied by a detailed manifest separate from general records). Some inspections involve soil samples, while others do not. On average, a single inspection has between three and four areas. Inspections at Deepwater in the 1990s averaged over 23 areas apiece.

Are the monitoring decisions of New Jersey regulators motivated by anything other than the technical features of these plants? By any standard measure, the fabricated metal industry is less important to the New Jersey economy than the chemical industry. Fabricated metal is the sixth largest of twenty manufacturing industries in the state (33rd of 70 standard industry categories), having employed 31,781 people out of a workforce of 3.3 million in 1997, or slightly less than one percent. The industry generates about seven-tenths of one percent of New Jersey's gross state product. The chemical and allied products industry, by contrast, is a larger contributor to the New Jersey economy than fabricated metal is. Its roughly 65,000 employees made it the largest manufacturing sector employer in the state in 1997 (14th out of 70 standard industrial categories), and it is responsible for 5 percent of gross state product.

The enormous differences between these two facilities and the state's response to them highlight the difficulty in distinguishing the degree, if any, to which regulators' targeting choices might be motivated by political considerations. The two plants are vastly different, and it would be foolish to assume that in the absence of any non-technical discriminatory motivations, they would face an equal likelihood of inspection at the same intensity. In the presence of constraints on the time and monitoring resources of the agency, a strategy of pure, unconditional equity would be remarkably inefficient. Even if one takes into account the relatively sparse population density of Salem County, the Dupont site is vastly more important than the Dri-Print site. A Type II error, or

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undetected violation, could be enormously costly at Deepwater. It is unlikely to be so dangerous at Dri-Print.

This heterogeneity suggests the limits of employing aggregate counts of agency actions as proxies for enforcement intensity, and the need for micro-level case data on enforcement practices. The need to control for the technical features of different facilities suggests the necessity of a multivariate statistical approach in assessing regulatory performance with case-level information. In order to gauge the influence of the features of the state political economy with which we are concerned, an analyst could gather information on the intensity of monitoring at different plants, and attempt to assess the association between intensity and industry strength, controlling as well as possible for the potential environmental harm that Type II errors might pose at the different plants. I will refer to this methodology the "reduced form" approach to the quantitative analysis of inspection. There are, unfortunately, several problems with this technique. Most obviously, it is difficult to control for plant characteristics and the level of harm that an undetected violation might cause.[6] But even if one were able to control for all the technical characteristics of individual facilities, such a methodology would still be problematic.

To begin with, the tendency of facilities to violate regulations on the books is endogenous to the agency's targeting efforts. Target one facility exclusively, and it will invest in reducing the frequency of its violations at the same time as other facilities that are not subject to agency scrutiny disinvest. There are, in other words, diminishing returns from over-targeting that emerge not only because the regulator might detect all the violations there are to find, but also because the number of those violations is itself determined by the level of monitoring. The targeting strategy of an agency comes about as the result not just of the technical features of individual plants, but of careful consideration of how regulated parties will react to the agency's monitoring behavior itself.

Second, if an agency's regulatory efforts are relaxed for some industries more than they are for others, this tendency is likely to pervade all aspects of the regulatory process, and not just

[6]Studies of racial discrimination in law enforcement, loan behavior, and employment face a similar hurdle. See, for example, Ayres and Waldfogel (1994); Van Order and Zorn (1995); and Epstein (1992).

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the monitoring stage. Suppose the agency is more likely to forgive sanctions against noncompliant facilities in a politically powerful industry. Holding the intensity of monitoring constant, if the regulator's threat to penalize is less credible for those industries, they will respond by disinvesting from compliance technology. Of course, the regulator knows this, meaning that she will have to scrutinize firms in those industries *more intensively* to compensate for inadequate sanctions. In other words, an inspector who foresees political problems in the penalty phase of the enforcement process may compensate with greater effort in the monitoring phase.

The complexity of the regulatory environment, the endogeneity of compliance, and the extent to which features of the state political economy influence different phases of the regulatory process each pose challenges that must be overcome to assess adequately the influence of political and economic features on that process. In the remainder of this chapter, I develop an approach suitable to addressing these difficulties, based on the analysis of "optimal auditing."

2.3 Regulatory Monitoring as an Optimal Auditing Problem

The literature on optimal auditing has its origins in the seminal work of Becker (1968) and Stigler (1970) on the economics of crime. Early literature examined the behavior of agents given an exogenously specified penalty for noncompliance and probability of monitoring. Later, game-theoretic treatments have considered the equilibrium behavior of both regulators and regulated parties when the choice to monitor is determined endogenously. Consider, for example, the inspection game, a simple model often described in game theory textbooks (e.g., Fudenberg and Tirole 1991, 17-18). The strategic form for a version of the game is displayed in Figure 1.

There are two players, a regulator and a firm. The firm must decide whether to comply with the law or not comply, and the regulator whether to inspect or not inspect. If the regulator monitors, the firm strictly prefers observing the law, as the cost of compliance y is smaller than the cost of the sanction s. If the regulator doesn't monitor, the payoff for compliance falls below the payoff for noncompliance, which is normalized to zero. In that situation, the firm prefers to violate the law. At the same time, the regulator prefers to inspect if the firm does not comply, as the cost

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Figure 1: *A Simple Inspection Game in Strategic Form*

Firm		Regulator: Inspect	Regulator: No Inspect
	Comply	(-y,-b)	(-y,0)
	Don't Comply	(-s,-b)	(0,-t)

Note: $s > y > 0$ *and* $t > b > 0$.

of an inspection b is smaller than the cost of the undetected violation t. If the firm does comply, the regulator prefers not to inspect (in which case her payoff is zero). The regulator and firm move simultaneously.

Readers familiar with basic game theory will note that there is no pure strategy Nash equilibrium to this game. This means that there is no pair of moves by the regulator and firm that are best responses to each other. Allowing the parties to play probabilistic, mixed strategies, there is a unique equilibrium. Let σ_R and σ_F represent, respectively, the probability that the regulator inspects and the firm complies. The Nash equilibrium sets $\sigma_R = y/s$ and $\sigma_F = (t - b)/t$. The model is instructive because it suggests a situation in which the regulator's actions are undertaken in consideration of the firm's payoffs, and vice versa (Tsebelis 1989, 1991). The regulator, for example, bases the likelihood of monitoring on the cost of compliance relative to sanction. This feature formalizes the pitfalls of the reduced form multivariate approach discussed in the previous section. If a firm's political power permeates the inspection process by increasing the cost to the regulator of monitoring, this advantage will manifest itself in the firm's compliance decision. If that same power results in lower penalties for noncompliance, then the advantage will manifest itself in the regulator's monitoring decision. Examining the inspection decision in isolation does not permit the analyst to sort out, or even account for, these effects.

While the simple inspection game is useful as a heuristic device, there are several limita-

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tions to its applicability as a model of hazardous waste monitoring. First, the choices available to the inspector and regulated party are far more varied than the stark, binary strategy spaces described in the simple game. To be sure, facility managers may decide to engage in illegal, "midnight" dumping of hazardous waste material, thus consciously choosing to violate the law (Hammitt and Reuter 1988; Sigman 2000). In most cases, however, a manager's decision concerns a level of compliance expenditures or degree of diligence or attention to regulatory affairs (Kelman 1980; Brehm and Hamilton 1996). Further, there is a random component to the occurrence of violations at plants. A firm may spend little on compliance and still, because of the peculiar characteristics of the manufacturing process or economic conditions at the time, not violate regulations. Likewise, a diligent manager who prioritizes compliance may fall victim to a lazy handler or worker on the shop floor. The regulator's choice set is similarly richer than the stark decision of whether or not to monitor. The regulator can choose a level of monitoring intensity that she considers appropriate. She can send one inspector or many to a facility, or keep an inspector on site for days or months. Also, detection of noncompliance has a random component, as inspectors may inadvertently overlook violations.

Second, hazardous waste regulators must decide not whether to monitor a single firm, but rather, how to disburse their limited inspection resources across a universe of different regulated firms. The regulator's problem is therefore best thought of as one of optimal allocation.[7] Several similar optimal auditing models have examined the problem of allocating monitoring resources in the context of tax policy (Graetz, Reinganum, and Wilde 1986; Reinganum and Wilde 1987; Border and Sobel 1987; Scotchmer 1987). More recently, the problem of racial bias in motor vehicles has been considered from the auditing standpoint (Knowles, Persico, and Todd 2001). In the taxation models, the auditor is usually assumed to maximize net revenue for the agency; while in the motor vehicle search example, the police officer seeks to maximize the number of successful drug arrests. In determining a monitoring allocation strategy, the regulator must consider four important facts. First, her strategy will induce regulated parties to adjust their compliance strategies. Second,

[7]For a recent allocation paper in political science, see Mebane, Ratkovic, and Tofias (2001).

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inspecting some parties is more costly than inspecting others. Third, resources are limited, so not all violations will be detected. Finally, while the regulator will try to maximize detected violations, some violations will "count" more than others. A detected violation at Dupont, for example, will carry more weight than one at Dri-Print.[8]

2.4 The Legal Context of RCRA Monitoring

When formulating a monitoring allocation strategy, hazardous waste regulators attempt to exploit available information about individual facilities and their geographic locations. These regulators have detailed information, from a biannual survey of all LQGs and treatment, storage, and disposal facilities, on the technical features of individual plants. They can also obtain computer-generated reports, either from the state or the federal government, on the compliance history of individual facilities. With these data, a regulator can form expectations about the type and severity of violations that one would likely encounter when visiting a site.

At the same time, a regulator's actual, finalized inspection schedule is one of the most closely guarded secrets in an agency. If plant managers knew with certainty precisely when they would be visited, they could act to guarantee compliance for the short time period for which they anticipated inspectors. At the same time, a manager who knew that inspectors were not targeting his plant could disinvest from compliance altogether. In the United States, the courts have generally upheld the prerogative of regulatory agencies to keep the reasoning behind their *specific* targeting decisions private, requiring only that the general principles of the targeting system be public. The Supreme Court, in a line of fourth amendment jurisprudence concerning regulatory agencies, has required that inspectors obtain search warrants at the request of the regulated party when Congress does not specifically authorize warrantless entry.[9] However, an agency regulating public health and safety need not demonstrate probable cause in order to obtain one. In *Marshall v. Barlow's*, the court held that targeting based on "neutral criteria" or a "general administrative plan" was

[8]How much more it should count is considered in the next chapter.

[9]See, for example, *Marshall v. Barlow's*, Inc., 436 U.S. 307 (1978); *Colonnade Corp. v. United States*, 397 U.S. 72 (1970); *Camara v. Municipal Court* 387 U.S. 523 (1967); and *See v. City of Seattle*, 387 U.S. 541 (1967).

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sufficient to satisfy fourth amendment concerns.

Once an inspection is conducted, a number of different events may take place. Some inspections end with no violations detected. Others end with uncertainty about a facility's noncompliance. Inspectors may return to the facility to conduct case development inspections, gathering additional information to use in an eventual enforcement action. If violations are detected, the regulatory agency enters into discussions with the facility's owners regarding how to address the problem. If the problem is severe and no good faith effort at compliance can be demonstrated, then the agency may commence a formal enforcement action against the facility. Civil penalties for a single violation can range up to a maximum of $25,000 per day out of compliance. Sometimes, the state agency will ask the federal EPA to conduct the enforcement action on its behalf when a case gets, as one regional manager put it, "politically hot." Occasionally, the EPA will undertake an enforcement action when the state agency declines to, in a process called "overfiling." Not surprisingly, this strategy usually breeds resentment among state officials. Instances of overfiling are highly publicized, but the tactic is rarely employed.

After a settlement or finding by an administrative law judge or in federal court, the facility's owners and the regulating agency enter a consent agreement to address the violation. Additional inspections may be carried out to insure compliance with the agreement. Finally, if a facility is deemed a significant non-complier, the EPA and state agency may impose on it a more stringent monitoring regimen.

3 The Model

In this section, I propose a model of the relationship between a single regulator and the parties under its jurisdiction, which are referred to interchangeably as facilities, firms, plants, or regulated parties. Plant managers must decide how much to invest in compliance technology given certain features of their facilities and their beliefs about the likely allocation of monitoring resources by the regulatory agency. The regulator, in turn, must decide how to allocate her finite monitoring

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resources. She does so based on a number of considerations, including her beliefs about the potential adverse environmental impact of violations at different plants, variation in the costs associated with inspecting certain facilities, and beliefs about the degree of compliance by the firms under the monitoring regime.

I derive first order conditions for equilibrium between the regulator and each of the regulated parties. Because certain features of the model are unknown to the researcher, I can present no analytic solution for the equilibrium described below. As a consequence, it is impossible directly to assess the influence of exogenous firm and industry characteristics on the intensity of monitoring. However, if the regulator's position as an agent induces her to maximize the number of detected violations weighted by their importance (net of the cost of monitoring), it is possible to assess the existence of these effects in equilibrium. At firms the regulator visits, she will allocate monitoring resources to equalize the marginal cost of an inspection with its marginal expected returns. Therefore, a firm's ability to impose political costs on the agency will be reflected in higher inspection returns at its facilities.

There are several limitations of the model. First, important elements of the political process are treated as exogenous. Most fundamentally, the relative political clout of certain facilities, captured by a parameter that simultaneously increases the cost of monitoring and discounts the firm's expected penalty in the event of detected noncompliance, is based on features that are not chosen by their managers in the game between themselves and the monitor. Developing a more complete model, in which the firm must trade off between investing in compliance technology and investing in lobbying the regulator, would add a layer of complexity not warranted given the focus of current attention (regulatory decision making), and so is left as a task for future work. Second, agents are "regulation takers," i.e. their strategic interaction is with the regulator alone, and not with other regulated parties. They cannot coordinate to share the burden of regulatory costs. It is the case that regulated parties can coordinate to lobby the agency and its political principals. However, this coordinative action is assumed to take place prior to the strategic interaction with the regulator.

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3.1 Regulatory monitoring when firm characteristics are known

Firms and their managers. There are N firms, indexed by $i = 1, 2, \ldots, N$. The number of violations generated at each facility is the realization of a Poisson process V_i, a mathematical representation of discrete, random events accumulating over time. The Poisson is chosen for its convenience in the context of the theoretical model; as will become clear in the next chapter, its limitations as a statistical estimator will not pose a problem for the empirical analysis. The violation-generating process at firm i can be described entirely by its intensity parameter, λ_i, which represents the expected number of events per unit time, $E[v_i]$, as well as their variance.[10] The rate depends in turn on two separate quantities.

The first of these is the firm's expenditures on compliance, y_i. These expenditures might represent investments in fixed technologies or personnel whose exclusive focus is regulatory affairs. Tough times economically may lead the firm to reduce its expenditures on compliance; so too might the deterrent effect of stringent monitoring or the threat of stiff penalties for noncompliance. The second is a facility-specific fixed effect, κ_i, which represents the base technology of the firm. A convenient expression of the relationship among these variables is $\lambda_i = \kappa_i/(1 + y_i)$. If the firm spends nothing on compliance ($y_i = 0$), $\lambda_i = \kappa_i$.[11]

For now I assume the κs are common knowledge. Firms are characterized by several additional parameters known both to the regulator and the firm. The first is a risk weight, $\omega_i > 0$, which corresponds to the seriousness or weight a violation at facility i carries with it in the eyes of the regulator. The second is a multiplier, $\tau_i > 0$, which represents the ability of a firm, by virtue of its electoral or economic strength or its credible threat of exit, to impose costs on the agency. τ_i, then, is a measure of raw industry political power. A $\tau_i < 1$ implies relative powerlessness or "negative influence." It is possible, for example, that the regulator takes psychological pleasure in inspecting

[10]Given parameter λ_i, the expected number of events in a time period of length Δ is, not surprisingly, $\lambda_i\Delta$. If V_i represents a running total of violations over time, the probability that k events occur in a time period of length Δ is $\Pr_i(V_i(t+\Delta) - V_i(t) = k) = \exp(-\lambda_i\Delta)(\lambda_i\Delta)^k/k!$.

[11]An alternative parameterization would distinguish firms by a unit cost of compliance expenditures, and hold firm-specific technology constant. The choice is substantively irrelevant, so I adopt the approach employed here for convenience.

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certain facilities – for example, if she is prejudiced against some plant owners or managers.

The regulator, whose behavior will be described in greater detail below, will allocate b_i of her monitoring budget B toward inspecting firm i. Visiting a plant does not guarantee that any or all violations will be detected, but monitoring more intensely increases the likelihood of detection. Let $\delta(b) : \mathcal{R}^+ \rightarrow [0,1]$ represent the regulator's "detection function" (Feinstein 1989, 1990), a mapping of monitoring intensity b to the probability that a realized violation is detected by the regulator. For technical reasons, I assume $\delta(b)$ is continuous and twice-differentiable. Further, I assume the returns to monitoring are increasing at a decreasing rate.[12]

The existence of a detection function allows for the possibility of Type II errors, or undetected violations. As Feinstein (1989, 116) explains, inadequate inspections imply that even frequent visits by regulators may not induce plant managers to invest sufficiently in compliance. As will become apparent below, the inadequacy of penalties implies that even if detection is close to assured, investment in compliance may be low or even nonexistent. In the current context, I do not consider the possibility of Type I error (false detection). Regulators must identify and provide evidence of the existence of each specific violation. In hazardous waste regulation, this takes place during the process of case development, which can extend for months after the initial inspection.

The firm's managers, in deciding how much to spend on compliance, must weigh the cost of compliance expenditures against the expected cost of detected noncompliance. Call firm i's expected sanction for a single detected violation ξ_i. The firm's expected payoff from the regulatory process is

$$-\frac{\xi_i \delta(b_i) \kappa_i}{(1+y_i)} - y_i.$$

The first term on the right side captures the firm's expected enforcement costs: the likely number of *detected* violations multiplied by the expected penalty for each violation.[13] The second term

[12]Formally, $\delta'(b) > 0$ and $\delta''(b) < 0$.

[13]The firm does not pay for undetected violations in the form of adverse health effects. Introducing such an effect would be mathematically equivalent to making compliance investment less costly to the firm.

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represents the firm's compliance expenditures.

We can determine the plant managers' optimal strategy conditional on the regulator's monitoring intensity at that firm by finding a value of y that maximizes the payoff. That value, suppressing the subscripts for convenience, is

$$y = \max\left(0, -1 + \sqrt{\xi\kappa\delta(b)}\right) \equiv y^*(b),$$

Note that there is a range of parameter values for which the firm will spend nothing on compliance technology, even in the presence of a monitoring and enforcement mechanism. Zero expenditures occur when $\delta(b) \leq 1/\xi\kappa$. Because the detection function by construction cannot exceed one, this implies that if the product $\xi\kappa$ is less than one, the firm *never invests in compliance technology*, no matter how much the agency monitors it. Paying penalties as detected violations accumulate is simply the cost of doing business. When the firm exceeds the threshold and does expend resources on compliance, the relationship between $y^* > 0$ and the other variables is straightforward: The firm invests more when the expected penalty and inspection frequency are high, and when the firm's base technology causes it to generate frequent violations. It is worth noting that the relationship between κ and y^* helps explain why environmental activists remain skeptical when an historically severe polluter spends large and highly visible sums on environmentally friendly technologies (Lucas 1994). Although these investments may stem from benevolence or altruism, under a credible enforcement system it is purely in the firm's interest to make them.

The intensity of the violation generating process in equilibrium, λ^*, depends on the chosen value of y^*, which in turn depends on the facility's political and technical attributes and the monitoring intensity b. If there are no expenditures ($\delta(b) \leq 1/\xi\kappa$), then the expected number of violations in equilibrium is simply κ. If there are expenditures ($\delta(b) > 1/\xi\kappa$), then the expected number of violations is

$$\frac{\kappa}{1 + y^*(b|\delta(b) > 1/\xi\kappa)} = \sqrt{\frac{\kappa}{\xi\delta(b)}} \equiv \lambda^*(b|\delta(b) > 1/\xi\kappa). \quad (1)$$

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The regulator's monitoring strategy. The regulator has B resources to allocate, and wishes to maximize the number of detected violations weighted by their importance, net of the cost of the allocation. Monitoring costs stem from two separate sources. The first is the base technology of the firm, κ_i. When a firm's base technology leads it to generate more violations, more resources must be allocated to uncover them. The hazardous waste office of the Illinois Department of Natural Resources, for example, monitors both Warner Brake and Clutch in Roscoe and the Mobile Oil refinery in Joliet. Both are classified large quantity generators, but a record review at the latter will be more time-consuming than at the former. The second is the relative political cost of monitoring, τ_i. Only the cost κ will factor into the agency's budget constraint, however, as there are no ex ante limits on the amount of political capital the agency can expend on monitoring. By contrast, there are a finite number of inspectors at the agency's disposal. The regulator chooses an *allocation profile* $\vec{b}$, an $N \times 1$ vector of (nonnegative) monitoring intensities, to maximize her net payoff subject to this technical budget constraint. Given each firm's optimal y^* and the resulting expected number of violations, the agency's objective is:

$$\max_{\vec{b}=(b_1,b_2,\ldots,b_N)} \sum_{i=1}^{N} [\delta(b_i)\omega_i\lambda_i^*(b_i) - \tau_i\kappa_i b_i] \quad \text{s.t} \sum_{i=1}^{N} \kappa_i b_i \leq B \quad \text{and} \quad b_i \geq 0 \quad \text{for all} \quad i. \tag{2}$$

In the appendix to this chapter, I derive the first order conditions necessary to obtain the regulator's equilibrium strategy. As stated above, they are too complex to be solved analytically. Several critical features of the model, the objective function and the regulator's equilibrium strategy emerge:

1. The number of detected violations (as distinguished from the total number of actual violations) at facility i, $\tilde{V}_i$, follows a Poisson distribution with intensity $\delta(b_i)\lambda_i^*(b_i)$.

2. The expected number of detected violations at firm i is increasing (at a decreasing rate) over the entire domain of b_i, even if the threat of enforcement induces heavy compliance expenditures by that facility.

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3. If $\lim_{b_i \to 0^+} \delta(b_i)\omega_i\lambda_i^*(b_i) < \tau_i\kappa_i b_i$, the agency will never monitor facility i.

4. At the facilities the agency does visit, the agency chooses b_i to satisfy the following relation: $\omega_i(\delta'(b_i)\lambda_i^*(b_i) + \delta(b_i)\lambda_i^{*'}(b_i)) = (\tau_i + L)\kappa_i$.

5. The *average equilibrium return* on an inspection at facility i (i.e. the total return at facility i divided by b_i) is increasing in the marginal cost of the inspection, $(\tau_i + L)\kappa_i$.

The first two features are not properties of equilibrium, but simply extensions of the way the model is formalized. I will ignore for the moment the Poisson formulation of the detection process, noting simply that this will prove useful in the empirical analysis of the next chapter. The second feature captures an important relationship between detection and deterrence: Net of the cost of monitoring, there is always a benefit for a detection-maximizing regulator to monitor more. No matter how intensely the agency inspects, the increase in expected detection return associated with a marginal increase in monitoring always outpaces the deterrent effect brought about by the firm's response to that increase. This may appear to be a technicality of little consequence, but it in fact has critical ramifications for the incentives of the regulator. There is never a situation in which it pays for the detection-minded monitor to slack off monitoring out of concern for being too successful at deterrence.

The third property suggests that there may exist a class of facilities that will never be inspected. These correspond to the situation in which the cost of even the most miniscule degree of monitoring exceeds the benefit. Note that it is impossible to distinguish whether unmonitored facilities are passed over because of budget limitations, their political strength, or the technical cost of inspecting them. Also, there may be facilities for which the third property does not hold, but still are not visited. For example, the optimal strategy may be to monitor a facility at an arbitrarily small amount. However, because inspections occur at discrete intervals, the agency will opt not to visit the plant.

The fourth property describes the first order conditions corresponding to facilities the regulator does visit. This expression states that the expected weighted marginal return for an allocation

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b_i, i.e. the expected return from one additional unit of inspection resources, should equal the marginal cost. L, the Lagrange multiplier, represents the shadow cost of a finite budget, i.e. the degree to which resource limitations constrain the agency. The equal marginals conditions imply that if κ_i and τ_i were identical for all facilities, the expected marginal returns would be equalized across firms.

This leaves the fifth property of the model, which concerns the relationship between average equilibrium return and marginal cost. The ability to move from the marginal return/cost relationship in the fourth property to the average return relationship emerges from the declining marginal returns described in the second property. The capacity to relate average return with marginal cost is critical for an empirical test. While we cannot measure marginal inspection return when individual inspections vary in their intensity, we can measure average return.

The fourth and fifth properties that form the basis of the empirical tests in the next chapter are similar in spirit to the tests for racial prejudice suggested by Ayres and Waldfogel (1994) in their study of bail-setting, and Knowles, Persico, and Todd (2001) in their analysis of motor vehicle drug searches. Higher bail for, and more frequent traffic stops of minorities are not definitive evidence of racial prejudice, because race may be correlated with unobservable defendant and motorist characteristics. A lower flight risk for minority defendants (which would be reflected in lower rates charged by bail bondsmen), or a lower rate of success detecting drugs among minority motorists is evidence of racial prejudice, as it indicates a "taste for discrimination" (Becker 1957) operating contrary to efficient bail-setting or drug search strategy. A lower flight risk would indicate minority defendants are "over-deterred" relative to their white counterparts. A lower detection rate would suggest that troopers could improve their yield of detected drugs by shifting finite monitoring resources from minority to white motorists.

Another useful analogy (owed to John Londregan) concerns mining. Suppose we were interested in the impact of geographic conditions on the decision by a mining company of how to allocate its labor and capital. The mining company has access to several locations, which vary in the difficulty of the surrounding terrain (i.e. the marginal cost of mining). With knowledge of

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the geographic features of the sites, one could model the allocation as a function of those features. The main problem is omitted variables bias: we don't know whether those features are correlated with the inherent quality of the veins being tapped, which is difficult to observe. We do know, however, first that the company wishes to maximize profits, and second that the ore quality, which is observable, declines as the mine is tapped. An equilibrium prediction, then, is that mines that are more difficult to reach will output, on average, higher quality ore.

3.2 Regulatory monitoring when firm characteristics are obscured

The predictions of the model do not change appreciably if the regulator lacks information on the technical characteristics of individual facilities. This is because the agency can form expectations about those features based on their more easily observable characteristics. Regulated parties, in reaction, will adjust their compliance strategies to take advantage of the regulator's relative ignorance.

In environmental regulation, facilities are usually classified by industry category. For example, in the 1990s the EPA has initiated sector initiatives, wherein a single industry (usually categorized by two-digit SIC code) with a history of high noncompliance is singled out for scrutiny. Suppose there are C categories, and each category c has N_c firms in it. We can characterize the regulator's beliefs about the technical characteristics of individual firms in category c as a probability distribution over possible values of κ. Let $F(\kappa|c)$ represent this distribution function for a given industry category C. The agency's new objective is to maximize

$$\begin{aligned} &\sum_{c=1}^{C}\sum_{i=1}^{N_c}\int\left[\delta(b_i)\omega_i\lambda_i^*(b_i)-\tau_i\kappa_i b_i\right]\mathrm{d}F(\kappa|c) \\ =&\sum_{c=1}^{C}\sum_{i=1}^{N_c}\left[\delta(b_i)\omega_i\int\lambda_i^*(b_i)\mathrm{d}F(\kappa|c)-\tau_i\bar{k}b_i\right]. \end{aligned} \tag{3}$$

Note that the agency still has some facility-level information. Thus, even when she cannot distin-

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guish facilities by their base compliance rates, the regulator will still not monitor facilities with equal intensity. When the regulator is relatively ignorant, categorizing facilities as a heuristic will result in inefficient targeting and adjustment within categories. Managers at facilities with relatively low κs in their category will be systematically overtargeted, and thus overdeterred relative to other plants in their class. At the same time, facilities with relatively high κs will be systematically underdeterred. This result is similar in spirit to the argument of Reingenaum and Wilde (1987), who consider the efforts of an IRS agent to target taxpayers within "audit classes," and the resulting reporting behavior of those taxpayers.

4 Implications

The first theme of this book is that regulators serve dual roles as both principals and agents in complex networks of authority relationships. This chapter offers a model to explain how they act as principals in a relationship with multiple agents. The way they perceive that task, however, is inescapably linked to their role as agents to multiple, politically motivated principals. The regulator's position of agency creates a system of incentives that depends on two central factors. First, because the success of regulatory implementation is difficult to gauge, regulators will face implicit pressure to pursue a detection-based, rather than a deterrence- or equity-based, general strategy. This strategy, as I have argued, may dominate irrespective of the ideology or partisanship of the regulator's political superiors. This argument, if true, helps to explain why the record of empirical studies attempting to document a relationship between principal partisanship and regulatory performance has been mixed: As a bureaucrat, the regulator faces the same incentives to detect violations no matter who is running the show.

The second means through which the regulator's position of agency manifests itself in its role as principal is in the differential ability of interested parties to influence the outcome of regulatory proceedings. The agency relationship between the regulator and the regulated is not rightly considered absolute, because regulated parties have recourse to political channels. Some

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may endeavor to lobby the agency directly, threatening to leave a state or lay off workers should the agency push too hard to get the party to comply. Others may lobby the agency's principals, issuing similar threats. As I argued in chapter 2, these threats are likely to be loudest when they come from parties belonging to industries that contribute a large share to a state's economy, because the downside risk of ignoring them is highest.

Although some regulated parties may be in a better position to impose political costs on an agency than others, the overall influence of those threats will depend on the institutional position of the regulator. This brings us to the second theme of the book, which is that some regulators are better insulated from these types of pressures than others. Those that are in better insulated will typically enjoy some sort of institutional autonomy that degrades the ability of interested parties to directly impose costs on the regulators themselves. In the context of federal "partial preemption" programs managed by the states, institutional autonomy is coupled with resource autonomy, as state regulators rely in part on national rather than state actors for their budgets. The second argument, therefore, leads to the prediction that a regulator's institutional setting will interact with characteristics of regulated parties to alter agency behavior. This chapter has provided the tools with which we can assess that behavior.

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Appendix: Properties of the Monitoring Game

Important Properties of the Inspection Process

Proposition 1. The number of detected violations at facility i follows a Poisson distribution with intensity $\delta(b_i)\lambda_i^*(b_i)$.

Proof. The number of violations generated at facility i is V_i, the realization of a Poisson process with intensity $\lambda_i^*(b_i)$. If each violation stands an equal chance $\delta(b_i)$ of being detected, then the number of detected violations, $\tilde{V}_i$, follows a binomial distribution with parameters V_i and $\delta(b_i)$. Karlin and Taylor (1994, 243-44) demonstrate that the unconditional distribution of $\tilde{V}_i$ will be Poisson with the intensity given above.

Proposition 2. The expected number of detected violations at firm i is increasing (at a decreasing rate) over the entire domain of b_i, even if the threat of enforcement induces heavy compliance expenditures by that facility.

Proof. By assumption, $\delta'(b) > 0$, and $\delta''(b) < 0$. There are two cases to consider. In the simpler case, b_i is sufficiently small that $\delta(b_i) < 1/\xi_i\kappa_i$, and no expenditure takes place. In that case, the expected number of detected violations at the firm is $\delta(b_i)\kappa_i$, the product of a constant and the detection function. This product is characterized by diminishing returns. In the second case, the firm does spend resources on compliance. The expected number of detected violations, combining Proposition 2 and equation (1) is $\sqrt{\delta(b_i)\kappa_i/\xi_i}$. This is the product of a constant and the square root of a function that increases at a decreasing rate. The first derivative of this quantity is always positive, and the second derivative always negative:

$$\begin{aligned}\frac{\partial E\left[\tilde{v}^*\right]}{\partial b} &= \sqrt{\frac{\kappa}{4\xi}}\left[\delta(b)\right]^{-\frac{1}{2}}\delta'(b) > 0 \\ \frac{\partial^2 E\left[\tilde{v}^*\right]}{\partial b^2} &= -\sqrt{\frac{\kappa}{16\xi}}\left[\delta(b)\right]^{-\frac{3}{2}}\delta'(b) + \sqrt{\frac{\kappa}{4\xi}}\delta''(b)\left[\delta(b)\right]^{-\frac{1}{2}} < 0.\end{aligned}$$

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The Agency's Objective Function and Equilibrium Strategy

As noted in the text, the expected number of violations at facility i is κ_i if $\delta(b_i) \leq 1/\xi_i\kappa_i$, and $\sqrt{\kappa_i/\xi_i\delta(b_i)}$ otherwise. The regulator's objective is to maximize detected violations, weighted by their importance, net of the cost of allocation:

$$\max_{\vec{b}=(b_1,b_2,\ldots,b_N)} \sum_{i=1}^{N} [\delta(b_i)\omega_i\lambda_i^*(b_i) - \tau_i\kappa_i b_i] \quad \text{s.t} \sum_{i=1}^{N} \kappa_i b_i \leq B \quad \text{and} \quad b_i \geq 0 \quad \text{for all} \quad i.$$

Proposition 3. If $\lim_{b_i \to 0^+} \delta(b_i)\omega_i\lambda_i^*(b_i) < \tau_i\kappa_i b_i$, the agency will not monitor facility i. This simply states that if the expected return for even an arbitrarily small degree of monitoring is exceeded by its cost, it will never pay for the regulator to inspect the facility.

Call the set of facilities for whom the condition articulated in Proposition 3 does not hold S, and the number of facilities in that set N_S. The Lagrangian for the regulator's problem may be expressed as

$$\sum_{i\in S} [\delta(b_i)\omega_i\lambda_i^*(b_i) - \tau_i\kappa_i b_i] - L\left(B - \sum_{i\in S}\kappa_i b_i\right) + \sum_{i\in S} J_i b_i,$$

where the quantity L is the Lagrange multiplier for the budget constraint, and J_i is the multiplier for the ith nonnegativity constraint.

Proposition 4. At the facilities the agency does visit, the agency chooses b_i to satisfy the following relation: $\omega_i(\delta'(b_i)\lambda_i^*(b_i) + \delta(b_i)\lambda_i^{*\prime}(b_i)) = (\tau_i + L)\kappa_i$.

The Lagrangian yields $2N_S + 1$ first order conditions:

$$\left.\begin{array}{rcll} \omega_i\delta'(b_i)\kappa_i & = & (\tau_i + L)\kappa_i - J_i & \text{if} \quad \delta(b_i^*) \leq \frac{\tau}{\kappa} \\ \frac{\omega_i\delta'(b_i)}{2}\left(\frac{\kappa_i}{\xi_i\delta(b_i)}\right)^{\frac{1}{2}} & = & (\tau_i + L)\kappa_i - J_i & \text{otherwise.} \end{array}\right\} N_S \text{ equal marginals conditions}$$

$\vdots$

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$$\left.\begin{array}{rcl} L(B - \sum_{i \in S} \kappa_i b_i) & = & 0 \\ J_i b_i & = & 0 \forall i \end{array}\right\} N_S + 1 \text{ slack conditions}$$

The first N_S conditions equate the marginal return from an additional unit of monitoring at facility i with the marginal cost (which now incorporates the shadow cost of the budget). There are the also $N_S + 1$ complementary slack conditions arising from the constraints that are necessary for the system of equations to be identified. If the budget is limitless, the budget constraint is non-binding, so $L = 0$. Note, however, that even in the presence of an infinite budget, the agency will still not choose to monitor infinitely. If facility i is visited, its corresponding nonnegativity constraint is nonbinding, so $J_i = 0$.

Proposition 5. The *average equilibrium return* on an inspection at facility i (i.e. the total return at facility i divided by b_i) is increasing in the marginal cost of the inspection, $(\tau_i + L)\kappa_i$.

Proof. Denote the expected total detection return at facility i from allocation b as $TR(b) = \omega \tilde{V}(b)$, the average expected return $AR(b) = TR(b)/b$, and the marginal expected return $MR(B) = TR'(b)$. The change in AR associated with a unit shift in b is

$$\frac{dAR(b)}{db} = \frac{MR(b)}{b} - \frac{TR(b)}{b^2} = \frac{1}{b}\left[MR(b) - AR(b)\right]$$

In equilibrium, the marginal return $MR(b^*)$ must equal $\kappa(\tau + L)$. Substituting leads to the first order linear differential equation

$$\frac{dAR(b^*)}{db^*} + \frac{AR(b^*)}{b^*} = \frac{\kappa(\tau + L)}{b^*},$$

whose solution is

$$AR(b^*) = \frac{C}{b^*} + \kappa(\tau + L),$$

where C is an unidentified constant representing the equilibrium net utility gain from inspection.

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From proposition 2, it is known that the returns to monitoring are always increasing at a diminishing rate. This implies that if $\kappa(\tau + L)$ increases, b^* decreases, and so the fraction C/b increases. Thus any increase in the marginal cost must result in an increase in equilibrium average return.

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