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Effluent Limits, Ambient Quality, and Monitoring

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Carmen Arguedas, Dietrich Earnhart and Sandra Rousseau

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Carmen Arguedas
Departamento de Análisis Económico
Teoría Económica e Historia Económica
Universidad Autónoma de Madrid

Dietrich Earnhart
Department of Economics
University of Kansas

Sandra Rousseau
Faculty of Economics and Business
KU Leuven, Campus HUBrussel

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Contact Information for Corresponding Author:

Dietrich Earnhart
Department of Economics
University of Kansas
435 Snow Hall
Lawrence, KS 66045
Phone: 785-864-2866
Fax: 785-864-5270
Email: Earnhart@ku.edu

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Effluent Limits, Ambient Quality, and Monitoring

Abstract

Effluent limits are frequently based on a uniform emission standard, which applies to all polluting facilities within in a single industry. However, the implementation of many environmental protection laws does not lead to uniform effluent limits due to considerations of local environmental conditions. In this paper, we theoretically examine the relationships among the stringency of effluent limits imposed on individual polluting facilities, environmental protection agencies' monitoring decisions, and the ambient quality of the local environment. We then extend the theoretical analysis by exploring the establishment of effluent limits when (1) the national emission standard represents only an upper bound on the local issuance of limits and (2) negotiation efforts expended by both regulated polluting facilities and environmentally concerned citizens play a role. We find that the negotiated discharge limit depends on the political weight enjoyed and the negotiation effort costs faced by both citizens and the regulated facility, along with the stringency of the national standard and local ambient quality conditions.

Keywords: effluent limits, monitoring, inspections, environmental permits, wastewater, compliance

JEL codes: K42, L51, Q53, Q58

1. Introduction

Pollution control efforts begin with the issuance of effluent limits, followed by the monitoring of compliance with these limits on the part of regulated polluters and enforcement against non-compliant polluters. Frequently effluent limits are based on a uniform emission standard, which applies to all similar polluting facilities (e.g., same industrial classification). However, the implementation of many environmental protection laws in place around the world does not lead to uniform effluent limits due to considerations of local environmental conditions. In particular, implementation of the U.S. Clean Water Act does not issue effluent limits uniformly. Instead, each industry-specific Effluent Limitation Guideline represents only an upper bound on the issuance of any individual limit.[1] The actually issued limit reflects the minimum of the level identified by the Effluent Limitation Guideline and the level identified by an assessment of the ambient surface water quality of the water body receiving the wastewater discharge.[2]

The state water quality-based standard is designed to ensure that the ambient water quality of the receiving waterbody meets the state-based ambient quality standard, which in turn is designed to support the waterbody's designated use, e.g., fishing, swimming. In other words, the effluent limit is set so that the facility's discharges do not cause the water body's ambient water quality to fall below the acceptable level. Effluent limits identified by state water quality-based standards may differ across facilities and time since state water quality standards differ within a state and across states and ambient water quality conditions differ across space and time. In particular, due to state water quality standards, the same facility may face more stringent limits in different years or in different months of the same year; such monthly or seasonal variation is expected since state water quality standards depend on seasonal stream conditions (e.g., flow) and temperature.

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[1] Since the passage of the 1972 Federal Water Pollution Control Act, which preceded the Clean Water Act, the EPA has developed industry-specific Effluent Limitation Guidelines based on the degree of pollution reduction attainable by facilities in a given industry.

[2] This depiction indicates that permitted effluent limit levels are determined by Effluent Limitation Guidelines, which apply uniformly across all facilities within a particular industry, or ambient water quality concerns, which do not relate to an individual facility's ability to control discharges.

In practice, the water quality-based limit level becomes the binding effluent limit for several polluters. Thus, effluent limits differ across regulated polluters. U.S. environmental protection agencies are authorized and obliged to induce compliance with these differing levels of discharge limits using both monitoring inspections and enforcement actions. Yet U.S. environmental regulatory agencies enjoy great discretion over their monitoring decisions. Thus, varying effluent limits might influence monitoring decisions.

Although very relevant in practice, the theoretical literature on monitoring and enforcement has not explored the relationships among the stringency of effluent limits imposed on individual polluting facilities, environmental protection agencies' monitoring decisions, and ambient quality conditions (see the literature review in Section 2 below). Exploration of these relationships represents our first research objective. As our secondary research objective, we extend the analysis to explore theoretically the establishment of effluent limits when the national emission standard represents only an upper bound on the issuance of limits and negotiation efforts expended by both regulated polluting facilities and environmentally concerned citizens play a role.

We base our analysis on two theoretical models. In the basic model, a national regulator exogenously establishes the effluent limit level imposed on a representative polluting facility, while a regional agency is responsible for monitoring and enforcing the effluent limit. For this analysis, we consider two local environmental settings: strong assimilative capacity, which leads to "good" ambient water quality conditions (hereafter "good quality conditions"), and weak assimilative capacity, which leads to "bad" ambient water quality conditions (hereafter "bad quality conditions"). We find that variations in the discharge limit influence the regional agency's inspection decisions. Moreover, depending on the stringency of the discharge limit, the monitoring agency chooses either an inspection strategy that is uniform between the two considered settings of ambient water quality conditions – good versus bad – or an inspection strategy that differentiates between these two settings.

In the extended model, the regional administrative body also includes a permit writer, who is ultimately responsible for establishing the effluent limit imposed on the regulated facility, while the national regulator imposes an effluent standard that merely represents an upper bound on the effluent limit eventually imposed on the regulated facility. In the end, the permit writer endogenously selects the effluent limit level based on negotiation efforts expended by the regulated polluting facility and environmentally concerned citizens. We identify the conditions under which the effluent limit imposed on the regulated polluter differs from the national standard. These conditions relate to the political weight enjoyed and the negotiation effort costs faced by both citizens and the regulated facility, along with the stringency of the national standard and ambient quality. In general, we conclude that the application of a discharge limit is able to accommodate heterogeneity when different layers of government, such as local permit writers and monitoring agencies, are taken into account within the theoretical analysis.

The rest of the paper explores the identified research objectives. Section 2 identifies our study's contribution to the economic literature. Section 3 describes our basic theoretical model. Section 4 extends the basic model. Section 5 concludes. The Appendix provides all the proofs.

2. Contribution to the Literature

The present study contributes to two strands of literature: one strand that focuses on the interactions between regulatory stringency and enforcement strategies and another strand that investigates the political economy aspects of enforcement. Our results can also apply to other contexts. In this section, we discuss all of these issues.

Firstly, we contribute to the growing literature that theoretically explores the relationship between regulatory stringency and both monitoring and enforcement strategies (e.g., Arguedas and Rousseau, 2009; Arguedas, 2008; Jones and Scotchmer, 1990; Jones, 1989; Keeler, 1995; Harford and Harrington, 1991; Veljanovski, 1984). For example, Veljanovski (1984), Keeler (1995) and, more recently, Arguedas and Rousseau (2009) examine the influence of effluent limit levels on agency monitoring and/or enforcement behavior. However, in these studies, the standard is assumed to be exogenous, as opposed to the endogenous standard setting considered here. Arguedas (2008) explores the endogenous determination of effluent limits in a setting with costly monitoring and sanctioning, while focusing on the compliance incentives generated by particular policy combinations. However, Arguedas (2008) does not consider the hierarchical approach we take in our study and assumes that all of the policy parameters (the standard, the inspection probability, and the fine for non-compliance) are set by the same regulatory body. Jones and Scotchmer (1990) consider a hierarchical approach but assume that the standard is exogenous and the inspection agency focuses only on deterrence, as opposed to the more general objective function for the inspection agency considered here. Moreover, in Jones and Scotchmer (1990), the instrument used by the national regulator is the size of the budget allocated to the agency, while in our model the instrument used is the effluent standard. Saha and Poole (2000) and Decker (2007) also consider hierarchical settings but construct a federal government that sets the penalty for non-compliance and a local authority that engages in monitoring and enforcement. Particularly, Decker (2007) considers exogenous standards and constructs a setting in which the federal regulator, who is responsible for setting fines, seeks to minimize social costs, yet the local agency, who is responsible for enforcement, seeks to minimize the sum of (1) enforcement costs and (2) the reputational costs stemming from failures to undertake proper enforcement actions.

While all of these previous studies on regulatory stringency and monitoring and enforcement substantially improve our understanding of environmental agency behavior, to the authors' best knowledge, no previous theoretical study explores variations in effluent limit levels due to factors unrelated to the regulated entities' compliance costs and the effect of this variation on agency behavior.

Secondly, our analysis contributes to the literature that uses political economy models to study enforcement strategies (e.g., Makowsky and Stratmann, 2009; Garoupa and Klerman, 2010; Cheng and

Lai, 2012; Ovaere et al. 2013).[3] The study by Cheng and Lai (2012) is particularly relevant since it investigates the impact of interest groups on the regulatory stringency, while taking account of incomplete compliance. In the theoretical model, both shareholders of the polluting firms and environmentalists engage in lobbying and offer political contributions to the policymaker in order to influence the level of an emission tax. A somewhat surprising result of Cheng and Lai (2012) is that a stricter enforcement policy can lead to a higher actual emission level, particularly when the polluting firms have a relatively large political influence. Our model differs in several respects from the model presented in Cheng and Lai (2012): [1] we explore an emission limit rather than an emission tax; [2] we endogenously determine the monitoring strategy, while Cheng and Lai (2012) assume monitoring and sanctioning is exogenous; [3] we impose a binding upper standard on the emission limit, while Cheng and Lai (2012) do not constrain the regulatory agent's choice of the emission tax level; and [4] we allow a hierarchical structure of the regulating government, while Cheng and Lai (2012) model a single-layered government.

Thirdly, while our theoretical analysis draws upon the context of the U.S. Clean Water Act, our analysis extends to other environmental regulatory contexts meeting these three criteria: (1) legal requirements are constrained asymmetrically by national or supra-national standards, (2) tighter limits are imposed due to local ambient conditions, and (3) a separation exists between the authorities responsible for establishment of the standard, issuance of the effluent limits, and monitoring of compliance with limits. Most obvious, our analysis extends to regulatory efforts to control wastewater discharges from point sources in most developed countries. For instance, the European Water Framework Directive (2000/60/EC) requires a minimal amount of ecological and chemical protection everywhere in the EU by defining a set of ambient water quality standards; yet this same directive

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[3] Political economy models are used by many studies to explore various environmental policy settings, such as those relating to climate protection and trade. Several of these studies explore the effects of institutional changes on the stringency of environmental regulation, with some studies considering the role of lobbying: Fredriksson (1997), Damania et al. (2003), Binder and Neumayer (2005), Markussen and Svendsen (2005), and Gullberg (2008). However, these papers all assume full compliance and ignore the role played by enforcement policy.

obligates member states to establish more stringent requirements for identified zones where more protection is needed to support to particular uses (e.g., source of drinking water).

As important, our analysis extends to regulatory efforts to control air pollutant emissions from stationary sources in most developed countries. For example, the U.S. Clean Air Act dictates that tighter emission limit levels are imposed on stationary sources operating in counties that are out of attainment with National Ambient Air Quality Standards (Greenstone, 2002, 2004). As another example, Belgian environmental protection permits may account for local ambient conditions. Specifically, in Belgium, a regional agency imposes general permit requirements, which include effluent standards that are based on best available technologies or techniques; however, local administrators can impose effluent limits that are stricter, but not laxer, than the effluent standards, as needed in order to protect the local environment as guided by ambient standards (Lavrysen, 2009). Regardless of the permit stringency, the environmental inspectorate is responsible for monitoring and enforcing compliance with the limits.

Our analysis also extends to waste policy. For example, as part of its waste control efforts, the EU determines the minimal collection requirements for products, packaging, and waste associated with electrical and electronic equipment (e.g., WEEE Directive 2012/19/EU). However, EU member states' governments can raise their national or regional collection targets above any EU minimum. Consistent with this differentiation, while countries such as Belgium and the Netherlands impose high collection rates, other countries are struggling to achieve the EU minima (Dubois, 2013). As important, each EU member state is responsible for monitoring and enforcing these collection targets.

Lastly, our analysis also extends to pipeline safety efforts. For example, the U.S. Pipeline and Hazardous Safety Materials Administration (PHMSA) regulates pipelines by setting minimum federal standards with which all pipeline operators must comply, yet the Office of Pipeline Safety (OPS) [which lies within PHMSA], along with approved state regulators, implements the regulatory program by monitoring compliance and taking enforcement actions against non-compliance. Stricter set of controls are imposed in "high consequence" areas where the risk for damage to the environment, including human health, is greater (Stafford, 2012).

3. Basic Model without Negotiation over the Effluent Limit Level

This section presents the basic theoretical model in which the national regulator exogenously establishes effluent limit levels. Since our analysis focuses on the regulatory context of wastewater pollution, hereafter we use the more accurate technical terms of "discharges" and "discharge limits".

3.1. Model Setup

We consider a regional district subject to environmental regulation. In this district, a representative facility discharges pollution into a water body, while a national regulator and a regional agency interact to address the environmental problem. The national regulator sets a discharge limit to restrict discharges from the facility operating in the particular region, as well as a fine structure that applies if the facility is discovered exceeding the limit. The regional agency is responsible for enforcing the discharge limit and sets an inspection probability. The sequence of decisions is depicted in Figure 1.[4]

[INSERT FIGURE 1 ABOUT HERE]

We assume that the water body can possess one of two possible types of assimilative capacity α_j: strong assimilative capacity, which leads to good quality conditions, α_G, or weak assimilative capacity, which leads to bad quality conditions, α_B, such that $\alpha_B < \alpha_G$. Let e_{ij} denote the level of pollution discharged by representative facility of type θ_i into the water body of quality α_j, and let e_{ij}^o represent the discharge level without regulation in place, such that $e_{ij} \leq e_{ij}^o$. The facility can reduce its discharges at a cost depending on the discharge level and the facility's type. For simplicity, the facility can be one of two possible types, a high-abatement cost facility (θ_H) or a low-abatement cost facility (θ_L), such that $\theta_L < \theta_H$. The abatement costs of a facility of type θ_i are represented by the function

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[4] In this section, we do not explicitly model the limit and fine setting decisions of the national regulator. In Section 4, we allow the stringency of the discharge limit to be endogenously determined.

$c(\theta_i, e_{ij})$, such that $c_e(\theta_i, e_{ij}) < 0$ for all $e_{ij} < e_{ij}^o$, $c_e(\theta_i, e_{ij}^o) = 0$, and $c_{ee}(\theta_i, e_{ij}) > 0$ for all $e_{ij} \leq e_{ij}^o$.[5] For a given discharge level e, we assume that $c(\theta_H, e) > c(\theta_L, e)$, $c_e(\theta_H, e) < c_e(\theta_L, e)$, and $c_{ee}(\theta_H, e) \leq c_{ee}(\theta_L, e)$.[6]

The facility's discharges cause local environmental damages in the water body, which also depend on water quality α_j. Thus, environmental damages can be represented by the function $D(e_{ij}, \alpha_j)$ with $D_e(.) > 0$ and $D_{ee}(.) \geq 0$. For a given discharge level e, we assume that $D(e, \alpha_B) > D(e, \alpha_G)$ and $D_e(e, \alpha_B) \geq D_e(e, \alpha_G)$ [7].

The national regulator establishes the discharge limit and fine structure. The discharge limit is denoted as e_j^w. We assume that the limit does not depend on the type of the facility (θ_i), although it may vary between the two different qualities of the water body (α_j). We also assume that the fine structure for non-compliance is linear:[8]

$$F = f \cdot max\{0, e_{ij} - e_j^w\}, \text{ where } f > 0. \tag{1}$$

The regional agency is responsible for enforcing the discharge limit and sets an inspection probability for a facility of type θ_i discharging into a water body of quality α_j. This probability is denoted as p_{ij}, such that $0 \leq p_{ij} \leq 1$. The cost *per* inspection is $m > 0$. We assume that the regional agency has perfect information on the category to which a facility belongs; thus, discharges are perfectly known without inspection. However, monitoring is still needed to document formally a violation.

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[5] The first condition reveals that high abatement cost facilities face higher abatement costs than low abatement cost facilities when both types are discharging the same amount. The second condition indicates that high abatement facilities face higher marginal abatement costs. The third condition controls the curvature of the abatement cost function.

[6] The first two conditions indicate that marginal abatement costs are positive for all discharge levels below the level chosen when no regulation exists yet marginal abatement costs equal zero at the discharge level chosen when no regulation exists. The third condition controls the curvature of the abatement cost function.

[7] The first comparison indicates that damages are greater under bad water quality conditions than under good water quality conditions. As important, the second comparison reveals that marginal damages are greater under bad water quality conditions.

[8] In the concluding section, we assess the implications of a convex fine structure.

The objective of the (risk-neutral) facility is to choose the discharge level that minimizes the sum of abatement costs and expected fines. Therefore, for a given regulatory policy $\{e_j^w, f, p_{ij}\}$, a facility of type θ_i discharging into a water body of quality α_j solves the following problem:

$$\min_{\{e_{ij}\}} \left[c(\theta_i, e_{ij}) + p_{ij} f max\{0, e_{ij} - e_j^w\}\right] . \tag{2}$$

The inspection agency chooses inspection probabilities while considering abatement costs, environmental damages, and monitoring costs. Specifically, we assume that the agency's objective function is the following:

$$\min_{\{p_{ij}\}} \left[\psi c(\theta_i, e_{ij}) + D(e_{ij}, \alpha_j) + m p_{ij}\right] , \tag{3}$$

where $\psi \geq 0$ reflects the importance given by the inspection agency to abatement costs, relative to the sum of environmental damages and monitoring costs.[9]

After the limit e_j^w and the fine parameter f are made public, the agency announces the inspection probability p_{ij} for facility type $i \in \{H, L\}$ and water quality type $j \in \{G, B\}$. The facility then reacts to the environmental policy $\{e_j^w, f, p_{ij}\}$ by selecting its discharge level.

We solve the entire problem backwards in order to find the sub-game perfect equilibrium.

3.2. Decision Making

As part of this backward problem solving process, we discuss the decisions made by the facility and the regional agency in that order.

3.2.1. Facility

Given the policy $\{e_j^w, f, p_{ij}\}$, the objective of the (risk-neutral) facility is to choose the discharge level e_{ij} that minimizes the sum of abatement costs and expected fines, as expressed in (2). The solution to this problem is presented below in *Lemma 1*; the proof of the solution is presented in the Appendix.

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[9] Keeler (1995) introduces this same parameter ψ. If $0 < \psi < 1$, abatement costs matter but enjoy a lower priority than environmental damages and monitoring costs. If $\psi > 1$, then the agency's concerns about facilities' abatement costs dominate the other concerns.

Lemma 1. *Given* $\{e_j^w, f, p_{ij}\}$*, the optimal discharge level of the facility of type* θ_i *into a water body of quality* α_j*, denoted as* $\tilde{e}_{ij}$*, is identified by the following conditions*:

$$c_e(\theta_i, \tilde{e}_{ij}) + p_{ij} f \geq 0, \tag{4a}$$

$$e_{ij}^0 \geq \tilde{e}_{ij} \geq e_j^w, \tag{4b}$$

$$[c_e(\theta_i, \tilde{e}_{ij}) + p_{ij} f][\tilde{e}_{ij} - e_j^w] = 0. \tag{4c}$$

Therefore, the facility's optimal response to the regulatory policy is to comply with the discharge limit (i.e., $\tilde{e}_{ij} = e_j^w$) when the marginal expected fine for non-compliance is larger than the marginal abatement cost savings of exceeding the limit, i.e., when $p_{ij} f \geq -c_e(\theta_i, e_j^w)$.[10] However, the optimal response of the facility is to exceed the limit ($\tilde{e}_{ij} > e_j^w$) if the marginal expected fine lies below the marginal abatement cost savings evaluated at the limit. In that case, the facility chooses the discharge level that equates the marginal abatement cost savings and marginal expected fine, that is, $c_e(\theta_i, \tilde{e}_{ij}) + p_{ij} f = 0$. Note that $\tilde{e}_{ij} < e_{ij}^o$ as long as $p_{ij} > 0$.

From the above expression, we can easily define the minimum (or threshold) inspection probability that induces the facility of type *i* to comply with the legal limit as follows:

$$\bar{p}_{ij} = -\frac{c_e(\theta_i, e_j^w)}{f}. \tag{5}$$

Our assumptions ensure that $\bar{p}_{Hj} > \bar{p}_{Lj}$ since $c_e(\theta_H, e) < c_e(\theta_L, e)$. Moreover, for the case where the discharge limit does not depend on water quality ($e_G^w = e_B^w$), the threshold inspection probability does not depend on water quality either ($\bar{p}_{iG} = \bar{p}_{iB}$) since water quality does not affect abatement costs.

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[10] In a static model with deterministic discharges such as ours, the facility never chooses to reduce its discharge level strictly below the limit. This reduction merely increases abatement costs without any fine savings.

3.2.2. Regional Agency

The objective of the regional agency is to choose inspection probabilities that minimize the weighted sum of abatement costs, environmental damages, and monitoring costs, as expressed in (3), while taking into account the facility's best response, the legal discharge limit, and the fine:

$$\min_{\{p_{ij}\}} \left[\psi c(\theta_i, e_{ij}) + D(e_{ij}, \alpha_j) + m p_{ij}\right]$$

$$s.t. \qquad c_e(\theta_i, e_{ij}) + p_{ij} f \geq 0; e_{ij} \geq e_j^w; e_{ij} \leq e_{ij}^o \tag{6}$$

In order to describe the agency's inspection decisions, we identify e_{ij}^a as the inspection agency's preferred discharge level of a facility of cost type θ_i discharging into a water body of quality α_j. This discharge level satisfies the optimality condition:

$$\psi c_e(\theta_i, e_{ij}^a) + D_e(e_{ij}^a, \alpha_j) - m \frac{c_{ee}(\theta_i, e_{ij}^a)}{f} = 0. \tag{7}$$

Our assumptions guarantee the following ranking of the agency's preferred discharge levels: $e_{Lj}^a < e_{Hj}^a$ for all $j \in \{G, B\}$ and $e_{iB}^a < e_{iG}^a$ for all $i \in \{H, L\}$. Also, the larger is ψ (i.e., the larger is the weight the regional agency places on the facility's abatement costs), the larger is the preferred discharge levels e_{ij}^a, and vice versa. Based on *Lemma 1*, the inspection probability p_{ij}^a that induces each of these identified discharge levels is simply:

$$p_{ij}^a = -\frac{c_e(\theta_i, e_{ij}^a)}{f}. \tag{8}$$

The solution to the agency's optimization problem is presented below in *Lemma 2*; the proof of the solution is provided in the Appendix.

Lemma 2. *The regional agency's optimal inspection strategy, denoted as $\tilde{p}_{ij}$, depends on the level of the discharge limit as follows:*

$$\tilde{p}_{ij} = \begin{cases} p_{ij}^a, & e_j^w \leq e_{ij}^a \\ \bar{p}_{ij}, & e_j^w > e_{ij}^a \end{cases} \tag{9}$$

Therefore, as long as the legal discharge limit e_j^w is sufficiently strict (i.e., when the legal limit lies below the agency's preferred discharge level), the regional agency can implement its preferred discharge level by setting $\tilde{p}_{ij} = p_{ij}^a$. In this case, the facility exceeds the legal limit by selecting its discharges to equal the regional agency's preferred discharge level. However, for a sufficiently lax legal limit (i.e., when the legal limit lies above the agency's preferred discharge level), the optimal inspection strategy is $\tilde{p}_{ij} = \bar{p}_{ij}$, which leads the facility to comply with the limit.

The optimal inspection strategies and the induced discharge levels are depicted in Figures 2 and 3. Each figure shows how the optimal inspection probability and the induced discharge level change as the discharge limit varies. Specifically, the upper graph of each figure shows the relationship between the stringency of the limit and the optimal inspection probability, while the lower graph of each figure shows the resulting facility's best response to both the legal limit and the inspection probability. Figure 2 displays how these relationships differ between the two different water quality levels while considering the same facility cost type. Figure 3 displays how these relationships differ between the two facility cost types while considering the same level of water quality.

[INSERT FIGURES 2 AND 3 ABOUT HERE]

Figure 2 illustrates that the optimal inspection strategy depends on both the stringency of the discharge limit and the level of the water quality. As shown in the upper graph, when the uniform discharge limit lies at or below the agency's preferred level of discharges under bad water quality conditions (e_{iB}^a), the agency inspects more frequently when the facility is operating under bad water quality conditions than when the facility is operating under good water quality conditions. The extra monitoring pressure under bad conditions is needed to induce the agency's lower preferred discharge level. As shown in the lower graph, the agency's preferred discharges under bad water quality conditions, e_{iB}^a, are clearly less than the agency's preferred discharges under good quality conditions, e_{iG}^a. As long as the discharge limit lies below e_{iB}^a, both inspection probabilities and both discharge levels are independent of the discharge limit because the limit does not constrain the agency's choice.

Once the discharge limit rises above e_{iB}^{a}, as shown in the upper graph, the optimal inspection probability under bad water quality conditions begins to fall because the discharge limit constrains the regional agency's choice under these conditions. Since the agency cannot induce over-compliance with the discharge limit, the agency is resigned to inducing exact compliance with the discharge limit. As shown in the lower graph, the induced discharge level tracks perfectly with the discharge limit along the 45 degree line. As the discharge limit level rises further above e_{iB}^{a}, the monitoring pressure needed to induce exact compliance with a rising discharge limit falls, i.e., the optimal inspection probability drops.

Similarly, once the discharge limit rises above e_{iG}^{a}, the optimal inspection probability under good water quality conditions begins to fall. At discharge limit levels above e_{iG}^{a}, the discharge limit constrains the regional agency's choice even under good water quality conditions. Again, since the agency cannot induce over-compliance with the discharge limit, the agency is resigned to inducing exact compliance with the discharge limit. As shown in the lower graph, again the induced discharge level tracks the discharge limit along the 45 degree line. As the discharge limit level rises further above e_{iG}^{*}, the monitoring pressure needed to induce exact compliance falls.

Taken together, these conditions indicate that once the discharge limit lies above the agency's preferred discharge level under good water quality conditions ($e_{j}^{w} > e_{iG}^{a}$), the uniform discharge limit binds the agency's choice regardless of the water quality conditions. In this case, the agency is constrained to induce exact compliance whether quality conditions are good or bad, as shown in the lower graph. Consistently, the extent of monitoring pressure does not depend on water quality conditions, as shown in the upper graph.

When the discharge limit lies between e_{iB}^{a} and e_{iG}^{a}, the optimal inspection probability under bad water quality exceeds the optimal inspection probability under good water quality conditions, as shown in the upper graph. Even though the agency is constrained to induce only exact compliance under bad water quality conditions, so the inspection probability is lower than otherwise desired, the monitoring pressure needed to induce compliance exceeds the monitoring pressure needed to induce the agency's preferred discharge level under good quality conditions. Consistent with this difference, discharges under bad water quality conditions are lower than discharges under good water quality conditions, as shown in the lower graph.

Most interesting, the upper graph of Figure 2 shows that the regional agency implements a differentiated inspection strategy, under which the agency applies greater monitoring pressure under bad water quality conditions, as long as the discharge limit does not bind under good water quality conditions ($e_j^w < e_{iG}^a$). Once the discharge limit binds under both bad and good water quality conditions ($e_j^w \geq e_{iG}^a$), the regional agency implements a uniform inspection strategy under which the agency does not condition its monitoring pressure on water quality conditions.

Moreover, the lower graph of Figure 2 shows that the agency does not always induce compliance. When the discharge limit is sufficiently loose ($e_j^w > e_{iG}^a$), the facility is compliant regardless of water quality conditions. However, when the discharge limit is sufficiently tight ($e_j^w < e_{iB}^a$), the facility is non-compliant regardless of water quality conditions. In between these two extremes ($e_{iB}^a < e_j^w < e_{iG}^a$), the facility is compliant only under bad water quality conditions and non-compliant under good water quality conditions.

Figure 3 displays the relationships involving the optimal inspection strategy, the induced discharge level, and the imposed discharge limit for the two facility types and a given water quality level. The explanation of this figure is analogous to that of Figure 2. Here, the upper graph of Figure 3 shows that the regional agency always implements a differentiated inspection strategy, applying greater monitoring pressure under high costs, regardless of the discharge limit. The lower graph of Figure 3 shows that the facility is compliant when the discharge limit is sufficiently loose ($e_j^w \geq e_{Hj}^a$) and non-compliant when the discharge limit is sufficiently tight ($e_j^w < e_{Lj}^a$), regardless of the cost type.

In between these two extremes ($e_{Lj}^{a} \leq e_{j}^{w} < e_{Hj}^{a}$), only the low cost facility is compliant, while the high cost facility is non-compliant.

4. Extended Model: Negotiation over the Effluent Limit Level

In this section, we extend the basic model in order to understand better the setting of the discharge limit. We now include a permit writer, who is ultimately responsible for establishing the discharge limit imposed on the regulated facility.

4.1. Model Setup

As with the basic model, we consider decision making at three levels: national, regional, and facility. However, we now expand the regional administrative body so that the inspection agency lies within a larger regional authority composed of two independent branches: (1) an inspection agency, which is responsible for enforcing the discharge limit, as in the basic model, and (2) a permit writer, who is ultimately responsible for establishing the discharge limit imposed on the regulated facility. Given this expanded role for the regional authority, we re-interpret the national regulator's role in establishing the discharge limit. Now the national regulator imposes a discharge standard that represents an upper bound on the discharge limit eventually imposed on the facility. In this context, the permit writer must decide whether to impose a discharge limit equaling the national standard or to tighten the discharge limit to a level below the national standard. In this extended model, the permit writer's decision depends on negotiations with both concerned citizens and the regulated facility. Figure 4 illustrates this situation.

[INSERT FIGURE 4 ABOUT HERE]

This situation involves four stages. In the first stage, the national regulator sets a uniform discharge standard, denoted as $\bar{e}$, and a linear fine for non-compliance, again denoted as f. We purposively use the term "standard" for the discharge level set by the national regulator and the term "limit" for the discharge level set by the permit writer. We again treat this phase as exogenous.

In the second stage, the regional permit writer assesses the discharge limit to be imposed on the facility. Specifically, the permit writer gathers information from concerned citizens and the regulated facility and hears the concerns of both parties. Based on this information and these concerns, the permit writer may decide to tighten the discharge limit to a level below the national standard. The imposed discharge limit is again denoted as e_j^w even though it represents a "negotiated" discharge limit.[11] We label this phase as the permit hearing and writing phase.

In the third stage, the inspection agency, which is responsible for enforcing the negotiated discharge limit, e_j^w, sets the inspection probabilities, p_{ij}.

In the fourth and final stage, the facility selects its discharge level as its best response to the multi-faceted environmental policy $\{e_j^w, f, p_{ij}\}$.

Relative to the basic model, this extended model adds the permit hearing and writing phase. This phase demands additional structure in order to shape the analysis. First, we assume that citizens act as a collective environmental advocacy group. In this capacity, citizens aim to minimize the sum of expected environmental damages and the costs of their negotiation effort. Let $u > 0$ denote the unit cost of negotiation effort and g denote the amount of citizen negotiation effort. The citizens' objective is captured as follows:

$$\min_{\{g\}} \left[D\left(e_{ij}\left(e_j^w(g)\right), \alpha_j\right) + ug\right]. \tag{10}$$

Given this objective, the citizens' chosen amount of negotiation effort decreases with the cost of negotiation, u, but (weakly) increases with the discharge limit, e_j^w. The latter relationship follows because increasing the limit (weakly) increases environmental damages since discharges (weakly) rise as the limit grows, as shown in Figures 2 and 3. Thus, we can write the citizens' best response as $g = g(e_j^w, u)$, which involves the following partial derivatives: $g_{e_j^w}(e_j^w, u) \geq 0$ and $g_u(e_j^w, u) < 0$.

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[11] In this section, $\bar{e}$, denotes the discharge standard set by the national regulator, while e_j^w represents the discharge limit imposed by the permit writer. In the previous section, e_j^w denotes the discharge limit imposed by the national regulator. In both cases, e_j^w denotes the limit ultimately faced by the facility.

Second, the regulated facility minimizes the sum of abatement costs, expected fines for non-compliance, and its own negotiation costs. Let $v > 0$ denote the unit cost of the facility's negotiation effort and h denote the amount of facility negotiation effort. The facility's objective is captured as follows:

$$\min_{\{h\}} \left[c\left(\theta_i, e_{ij}\right) + p_{ij} f max\left\{0, e_{ij} - e_j^w(h)\right\} + vh\right]. \tag{11}$$

The facility pressures the permit writer so that he/she does not tighten the discharge limit since the sum of abatement costs and expected fines for non-compliance is decreasing in the discharge limit. Therefore, the amount of negotiation effort expended by the facility is a function of the discharge limit and the cost of negotiation, $h = h\left(e_j^w, v\right)$, which involves the following partial derivatives: $h_{e_j^w}\left(e_j^w, v\right) < 0$ and $h_v\left(e_j^w, v\right) < 0$.

Finally, the regional permit writer considers its own effort costs of tightening the discharge limit below the national standard and the costs of being confronted with negotiation efforts by citizens and the facility. The permit writer's effort costs of tightening the discharge limit are represented by $Z = Z\left(\bar{e} - e_j^w\right)$, such that $Z(0) = 0$ and $Z'(0) > 0$ for $\bar{e} = e_j^w$ yet $Z\left(\bar{e} - e_j^w\right) > 0$ and $Z'\left(\bar{e} - e_j^w\right) = 0$ for $\bar{e} > e_j^w$. This function represents the costs of obtaining information to prove that a tighter discharge limit might be needed in the region due to the region's idiosyncratic environmental circumstances. Also, we assume that the unit cost of being confronted with negotiation efforts by the citizens and the facility are respectively denoted as $\beta_g > 0$ and $\beta_h > 0$. The permit writer chooses the discharge limit level in order to minimize the sum of its tightening effort costs and confrontational costs subject to the restriction that the discharge limit level may not exceed the national standard and the response functions of the citizens and regulated facility:

$$\min_{\left\{e_j^w\right\}}\left[Z\left(\bar{e} - e_j^w\right) + \beta_g g + \beta_h h\right] \tag{12a}$$

$$\text{s.t.} \quad e_j^w \leq \bar{e}; g = g\left(e_j^w, u\right); h = h\left(e_j^w, v\right), \tag{12b}$$

where g(·) and h(·) respectively capture the negotiation efforts of the citizens and the regulated facility as responses to the discharge limit set by the permit writer.

Figure 5 presents the timing of the interaction involving the national regulator, permit writer, inspection agency, and facility. We solve the model backwards in order to identify the subgame perfect equilibrium.

[INSERT FIGURE 5 ABOUT HERE]

4.2. Decision Making

When solving the model backwards, we examine in order the decision making of the facility, agency, and permit writer. As shown in Figure 5, Stages 1, 3, and 4 are exactly the same as those presented in the basic model. *Lemma 1* presents the optimal response of the facility regarding its discharge level (Stage 4), while *Lemma 2* presents the regional agency's optimal inspection probability (Stage 3). Moreover, Figures 2 and 3 remain valid as graphical illustrations of the results connected with these two stages. Stage 1 reflects only the national regulator's exogenous determination of the upper bound on the discharge limit along with the linear term of the fine function. Therefore, in this sub-section we concentrate on the new component of Stage 2: permit hearing and writing phase.

As described in (12), the permit writer seeks to minimize the sum of effort costs and confrontational costs, constrained by the national regulator's upper bound standard on the discharge limit and the response functions of the citizens and facility. Given this objective and these constraints, we identify the permit writer's optimal discharge limit in *Proposition 1* below.

Proposition 1. *Given the national regulator's choice of discharge standard and fine parameter* $(\bar{e}, f)$, *the optimal discharge limit set by the permit writer satisfies the following conditions:*

$$Z'\left(\bar{e} - e_j^w\right) - \beta_h h_{e_j^w}\left(e_j^w, v\right) \geq \beta_g g_{e_j^w}\left(e_j^w, u\right), \tag{13a}$$

$$\bar{e} \geq e_j^w, \tag{13b}$$

$$\left[Z'\left(\bar{e} - e_j^w\right) - \beta_h h_{e_j^w}\left(e_j^w, v\right) - \beta_g g_{e_j^w}\left(e_j^w, u_g\right)\right]\left[\bar{e} - e_j^w\right] = 0. \tag{13c}$$

We explore these three conditions. Consider the first optimality condition – equation (13a). The term $Z'(\bar{e} - e_j^w) - \beta_h h_{e_j^w}(e_j^w, v)$ lies on the left hand side of equation (13a). This term represents the marginal cost of tightening the discharge limit, which is composed, respectively, of the marginal cost of the administrative effort needed to tighten the limit and the marginal cost of being confronted with increased negotiation effort by the regulated facility. The term $\beta_g g_{e_j^w}(e_j^w, u)$ lies on the right hand side of equation (13a). This term represents the marginal benefit of tightening the discharge limit as captured by the permit writer's marginal cost savings of being confronted with less effort by citizens. The second optimality condition – equation (13b) – simply reflects the binding nature of the national regulator's discharge standard, which represents an upper bound on the discharge limit. The third optimality condition – equation (13c) – combines the first two components as part of the Kuhn-Tucker conditions (see the Appendix for details).

In sum, *Proposition 1* tells us that it is optimal for the permit writer to <u>not</u> tighten the discharge limit, so that e_j^w remains equal to $\bar{e}$, as long as $Z'(0) - \beta_h h_{e_j^w}(\bar{e}, v) \geq \beta_g g_{e_j^w}(\bar{e}, u)$. This condition holds when the marginal costs of tightening the limit outweigh the corresponding marginal benefits, evaluated at $e_j^w = \bar{e}$. On the other hand, it is optimal to tighten the limit, so that $e_j^w < \bar{e}$, when the opposite condition is met. This condition holds when the marginal costs of tightening the limit are lower than the corresponding marginal benefits, evaluated at $e_j^w = \bar{e}$. In this latter case, the optimal discharge limit set by the permit writer satisfies the first optimality condition by equating marginal costs and marginal benefits: $Z'(\bar{e} - e_j^w) - \beta_h h_{e_j^w}(e_j^w, v) = \beta_g g_{e_j^w}(e_j^w, u)$.

Based on our assessment of the optimality conditions shown in (13), we are able to identify the conditions under which the discharge limit set by the permit writer equals the national standard. First, we immediately see that the discharge limit equals the national standard as long as the citizens possess insufficient political weight; for example, in the extreme case where citizens have zero political weight, β_g= 0, the marginal benefits of tightening the limit below the standard become zero. Second, the discharge limit equals the national standard when either the citizens' negotiation effort costs are large enough or the facility's negotiation effort costs are small enough. Third, the discharge limit set by the permit writer equals the national standard when the latter is already sufficiently strict. In terms of the relationships shown in Figure 3, this condition corresponds to the case of a national standard set below the agency's preferred discharges of the low cost facility: $\bar{e} \leq e_{Lj}^{a}$. In this case, tightening the discharge limit even more has no effect on environmental damages since the facility does not reduce its discharges when the limit lies below e_{Lj}^{a} because the agency does not exert the monitoring pressure needed to induce discharges below e_{Lj}^{a}. As a result of the agency's choice, it is worthless for citizens to exert any negotiation effort. Given a particular standard $\bar{e}$, the greater is the importance given by the inspection agency to the facility's abatement costs (i.e., the larger is ψ), the larger is e_{Lj}^{a}. Therefore, the condition of $\bar{e} \leq e_{Lj}^{a}$ is more likely met. Consequently, the discharge limit imposed by the permit writer is more likely to equal the national standard. Fourth, the discharge limit is more likely to equal the national standard under good water quality conditions than under bad water quality conditions. Figure 2 helps to explain this conclusion. Since $e_{iB}^{a} < e_{iG}^{a}$, the national standard is more likely to lie below e_{iG}^{a} than below e_{iB}^{a}. Therefore, citizens enjoy more leverage to exert negotiation effort under bad water quality conditions than under good water quality conditions. Under bad conditions, citizens are better able to reduce environmental damages by prompting the permit writer to tighten the discharge limit in the event that the national standard is set above e_{iB}^{a}.

In sum, the negotiated discharge limit depends on the political weight granted to citizens and the regulated facility by the permit writer, the negotiation effort costs borne by the citizens and regulated facility, the stringency of the national standard relative to the agency's preferred discharge levels, and water quality conditions.

5. Conclusions

In this paper, we study the relationships among the stringency of effluent limits imposed on individual polluting facilities, environmental protection agencies' monitoring decisions, and the ambient quality of the local environment. We first consider a basic setting in which the discharge limit is exogenous. In the extended model, we include negotiation efforts expended by regulated polluting facilities and environmentally concerned citizens to influence the establishment of the discharge limit by a permit writer.

Regarding the basic model, we find that the monitoring agency chooses either an inspection strategy that is uniform between the two sets of ambient water quality conditions – good versus bad – or an inspection strategy that differentiates between these two sets of conditions, depending on the stringency of the discharge limit. In contrast, the monitoring agency chooses an inspection strategy that differentiates between low cost facilities and high cost facilities independent of the discharge limit stringency. Regarding the extended model, we identify the conditions under which the discharge limit imposed on a regulated polluter differs from a national standard, which represents an upper bound on the limit. In particular, the negotiated discharge limit depends on the political weight granted to citizens and the regulated facility by the permit writer, the negotiation effort costs borne by the citizens and facility, the stringency of the national standard relative to the agency's preferred discharge levels, and water quality conditions. Thus, the application of a discharge limit is able to accommodate heterogeneity when different layers of government, such as local permit writers and monitoring agencies, are taken into account within theoretical analysis.

We next assess the implications of relaxing certain assumptions. As one assumption, we model a linear fine structure. If we instead consider a convex fine structure, Figures 2 and 3 must be modified. The main modification concerns the effect of the discharge limit level on the facility's chosen discharge level. Since the marginal fine in this case is increasing in the degree of non-compliance, a lower limit induces a lower discharge level. In terms of Figures 2 and 3, this connection implies that the facility's best response under non-compliance is no longer horizontal but increasing in the discharge limit, with a slope less than 1, which reflects the fact that a lower discharge limit leads to a larger degree of non-compliance. Given this relationship under a convex fine structure, concerned citizens are inclined to negotiate a reduction in the discharge limit below the national standard even when the standard lies below e_{iB}^{a} or e_{Lj}^{a}, depending on circumstances, since the monitoring agency is now able to induce further reductions in the facility's discharge level within the relevant range. Therefore, all else equal, the permit writer is more likely to tighten the discharge limit below the national standard under a convex fine structure than under a linear fine structure.

As another assumption, we posit that the regional agency's budget constraint is not binding. If we instead posit a binding budget, the likelihood of compliance decreases. In terms of Figures 2 and 3, this decrease implies that the range of discharge limit values that induce non-compliance expands. Since the facility's best response is constant under non-compliance, the presence of a binding budget decreases the likelihood that the permit writer tightens the discharge limit below the national standard, all else equal.

Lastly, we claim that our results apply to other environmental regulatory contexts beyond water quality protection. As important, we claim that our results are applicable to other realms of safety protection where the stringency of safety controls depends on the risk of damage to human safety, such as in the contexts of transportation safety, occupational safety, and product safety. For example, transportation speed limits are tighter in areas where children are likely to be playing, e.g., near schools; tighter occupational safety controls are imposed where pregnant women are working; etc. While our results should apply to these other contexts, future theoretical research should model these contexts explicitly.

APPENDIX

Proof of Lemma 1

The regulated facility never discharges a level below the limit e_j^w since the regulated facility would then incur additional abatement costs without additional benefits because fines are positive only for discharge levels above the limit. Therefore, we can write the Lagrangian of the facility's optimization problem as follows:

$$L(e_{ij}, \lambda) = c(\theta_i, e_{ij}) + p_{ij} f(e_{ij} - e_j^w) - \lambda(e_{ij} - e_j^w), \tag{A1}$$

where $\lambda \geq 0$ is the corresponding Kuhn-Tucker multiplier of the inequality restriction $e_{ij} \geq e_j^w$. The first-order conditions of this problem are the following:

$$c_e(\theta_i, e_{ij}) + p_{ij} f - \lambda = 0; \tag{A2a}$$

$$\lambda(e_{ij} - e_j^w) = 0. \tag{A2b}$$

Depending on the Kuhn-Tucker multiplier, two cases exist. In one case, $e_{ij} = e_j^w$ implies that $\lambda \geq 0$, which further implies that $c_e(\theta_i, e_j^w) + p_{ij} f \geq 0$. In the other case, $e_{ij} > e_j^w$ implies that $\lambda = 0$, which further implies that $c_e(\theta_i, e_{ij}) + p_{ij} f = 0$. The desired result is obtained by combining both cases and incorporating the condition that $e_{ij} < e_{ij}^0$ whenever $p_{ij} > 0$ ($e_{ij} = e_{ij}^0$ only if $p_{ij} = 0$).

Proof of Lemma 2

Assuming a positive inspection probability (which results in $e_{ij} < e_{ij}^0$) and identifying the threshold probability as $\bar{p}_{ij} = -\frac{c_e(\theta_i, e_j^w)}{f}$, we can write the optimization problem of the regional agency as follows:

$$\min_{\{p_{ij}\}} \left[\psi c(\theta_i, e_{ij}) + D(e_{ij}, \alpha_j) + m p_{ij}\right] \tag{A3a}$$

$$s.t. \qquad c_e(\theta_i, e_{ij}) + p_{ij} f \geq 0; e_{ij} \geq e_j^w; p_{ij} \leq \bar{p}_{ij} \tag{A3b}$$

The Lagrangian of this problem is the following:

$$L(p_{ij}, \lambda, \delta, \mu) = \psi c(\theta_i, e_{ij}) + D(e_{ij}, \alpha_j) - m\frac{c_e(\theta_i, e_{ij})}{f} - \delta(e_{ij} - e_j^w) + \mu(p_{ij} - \bar{p}_{ij}), \tag{A4}$$

where $\delta \geq 0$ and $\mu \geq 0$ are respectively the corresponding Kuhn-Tucker multipliers of the constraints $e_{ij} - e_j^w \geq 0$ and $p_{ij} - \bar{p}_{ij} \leq 0$. The first-order conditions of this problem can be written as follows:

$$\psi c_e(\theta_i, e_{ij}) + D_e(e_{ij}, \alpha_j) - m\frac{c_{ee}(\theta_i, e_{ij})}{f} - \delta = 0, \tag{A5a}$$

$$c_e(\theta_i, e_{ij}) + p_{ij} f = 0, \tag{A5b}$$

$$\delta(e_{ij} - e_j^w) = 0, \tag{A5c}$$

$$\mu(p_{ij} - \bar{p}_{ij}) = 0. \tag{A5d}$$

Depending on the value of the Kuhn-Tucker multiplier associated with the discharge limit level, two cases exist. On the one hand, $\delta = 0$ implies $e_{ij} = e_{ij}^a \geq e_j^w$, which is induced by p_{ij}^a, defined in (8). On the other hand, $\delta > 0$ implies $e_{ij} = e_j^w \geq e_{ij}^a$, which is induced by $\bar{p}_{ij}$, defined in (5).

Proof of Proposition 1

The Lagrangian of the permit writer's optimization problem is the following:

$$L(e_j^w, \lambda) = Z(\bar{e} - e_j^w) + \beta_g g(e_j^w, u_g) + \beta_h h(e_j^w, u_h) + \lambda(e_j^w - \bar{e}), \tag{A6}$$

where $\lambda \geq 0$ is the corresponding Kuhn-Tucker multiplier of the weak inequality restriction $e_j^w \leq \bar{e}$. We can write the first-order conditions of this problem as follows:

$$-Z'(\bar{e} - e_j^w) + \beta_h h_{e_j^w}(e_j^w, u_h) + \beta_g g_{e_j^w}(e_j^w, u_g) + \lambda = 0, \tag{A7a}$$

$$\lambda(e_j^w - \bar{e}) = 0. \tag{A7b}$$

Depending on the Kuhn-Tucker multiplier, two cases exist. In one case, $\lambda = 0$ implies that $-Z'(\bar{e} - e_j^w) + \beta_h h_{e_j^w}(e_j^w, u_h) + \beta_g g_{e_j^w}(e_j^w, u_g) = 0$ and $e_j^w \leq \bar{e}$. In the other case, $\lambda > 0$ implies that $Z'(0) - \beta_h h_{e_j^w}(e_j^w, u_h) \geq \beta_g g_{e_j^w}(e_j^w, u_g)$ and $e_j^w = \bar{e}$. Taken together, these two sets of conclusions demonstrate the desired result.

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Figure 1

Basic Regulatory Context

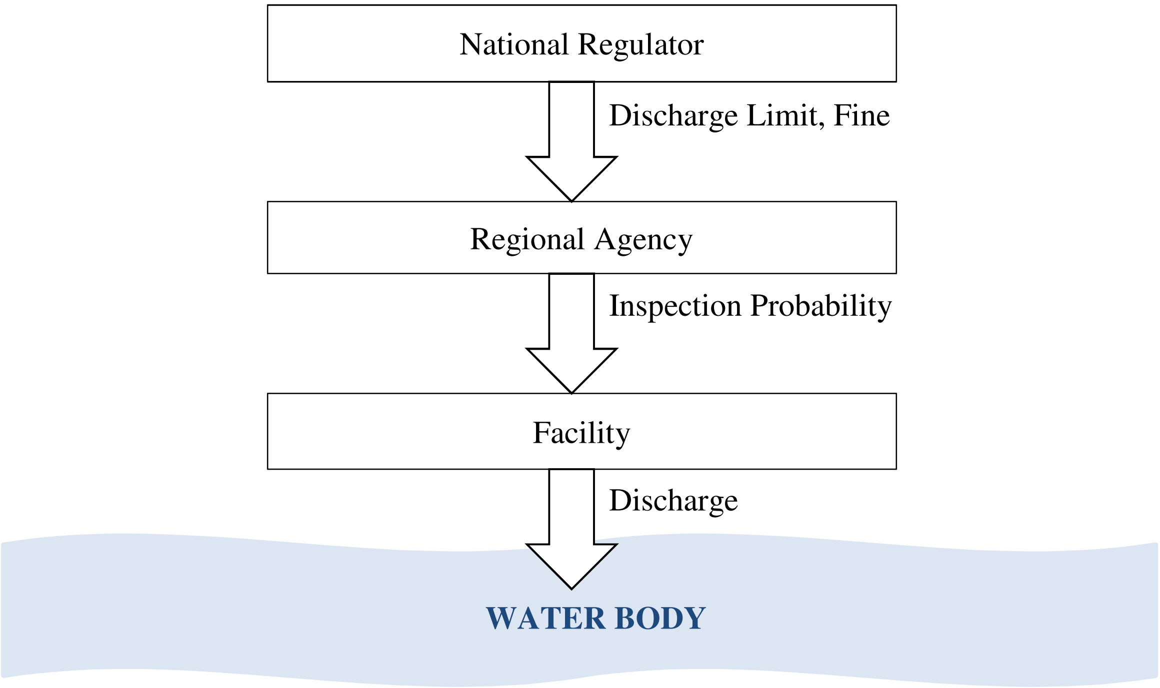

Figure 2

Optimal Inspection Strategy for a Given Facility Cost Type and Different Water Quality Levels

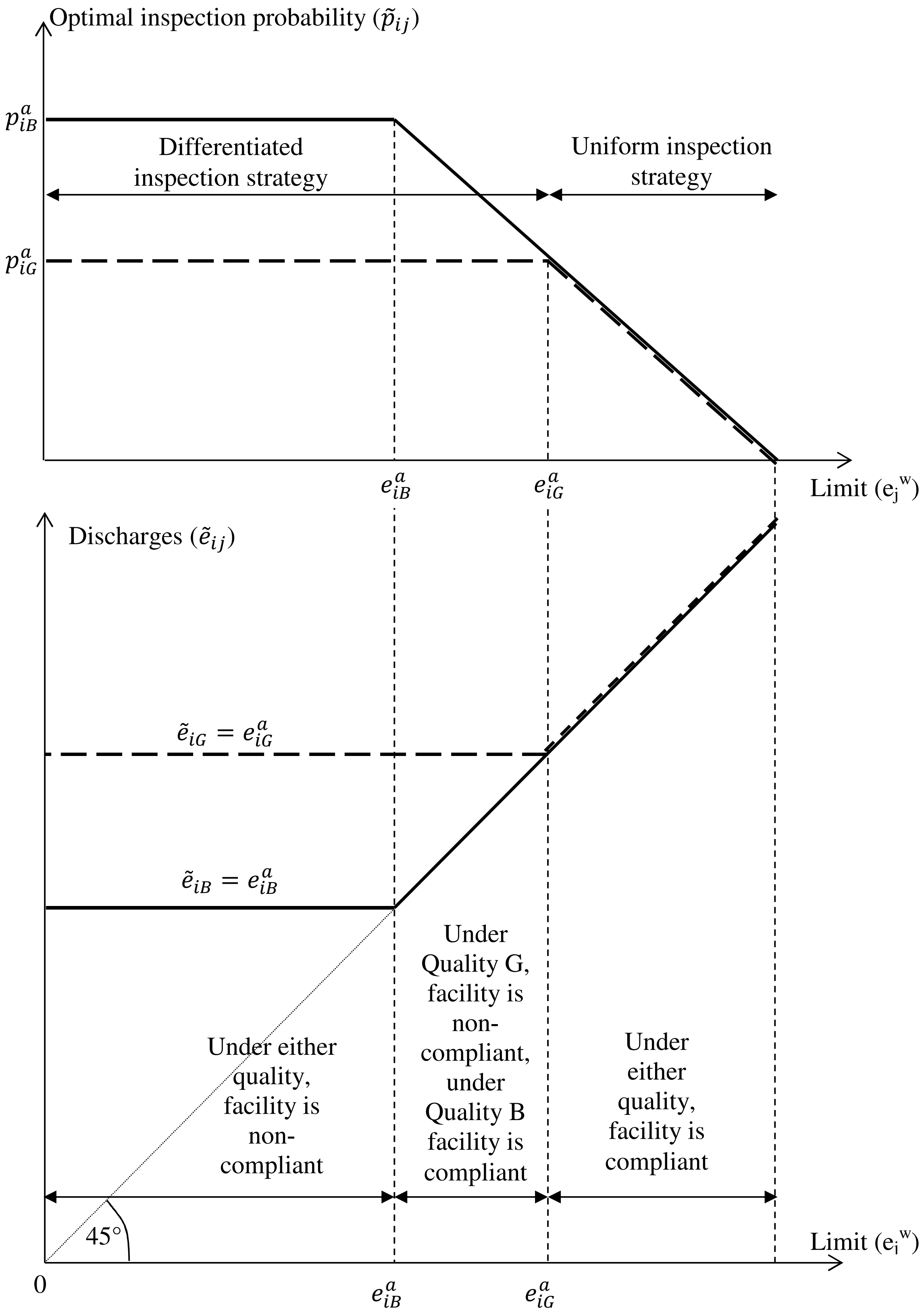

Figure 3
Optimal Inspection Probability for a Given Water Quality Level and Different Facility Types

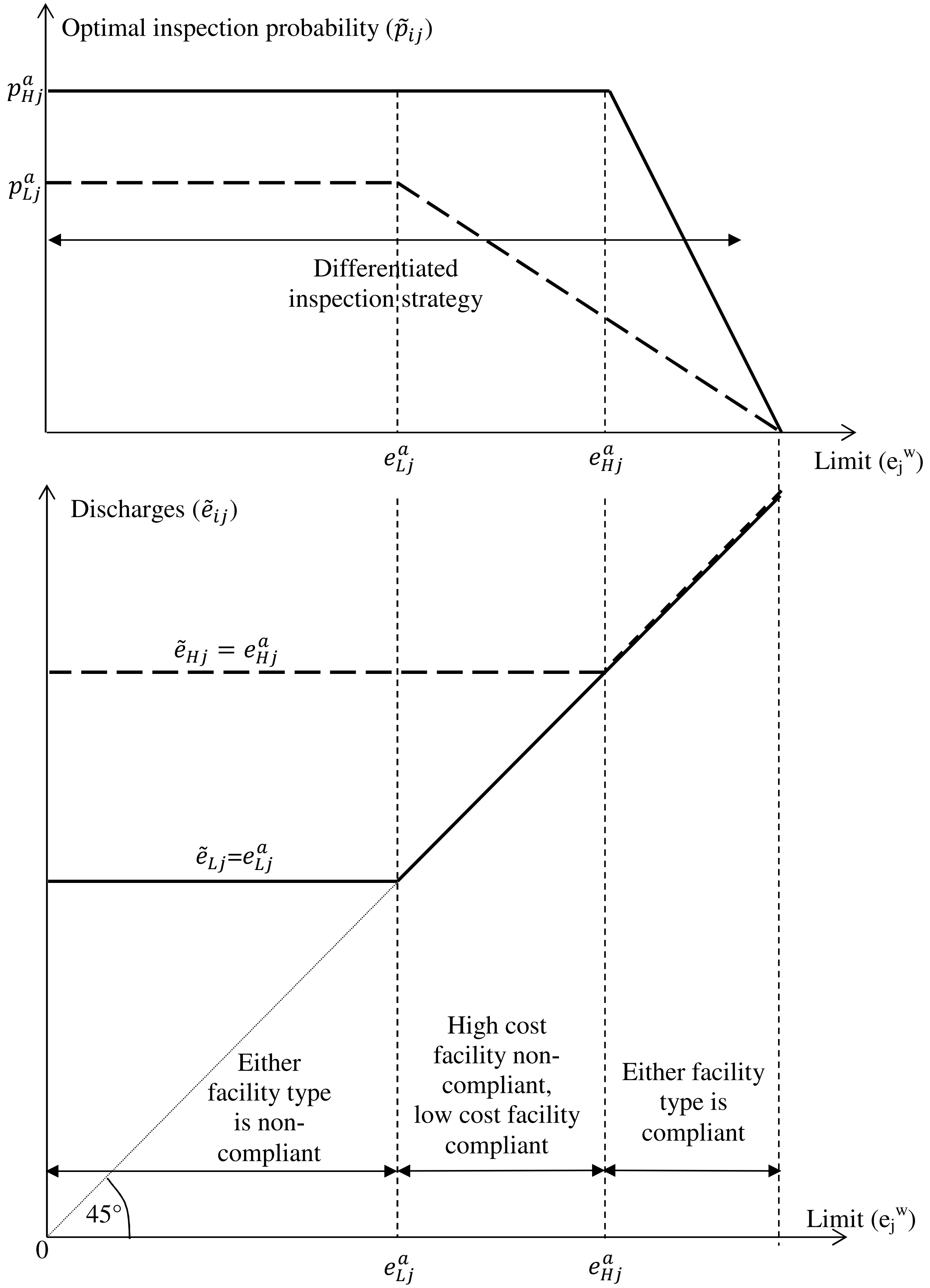

Figure 4

Regulation of Discharges under Negotiation over the Discharge Limit

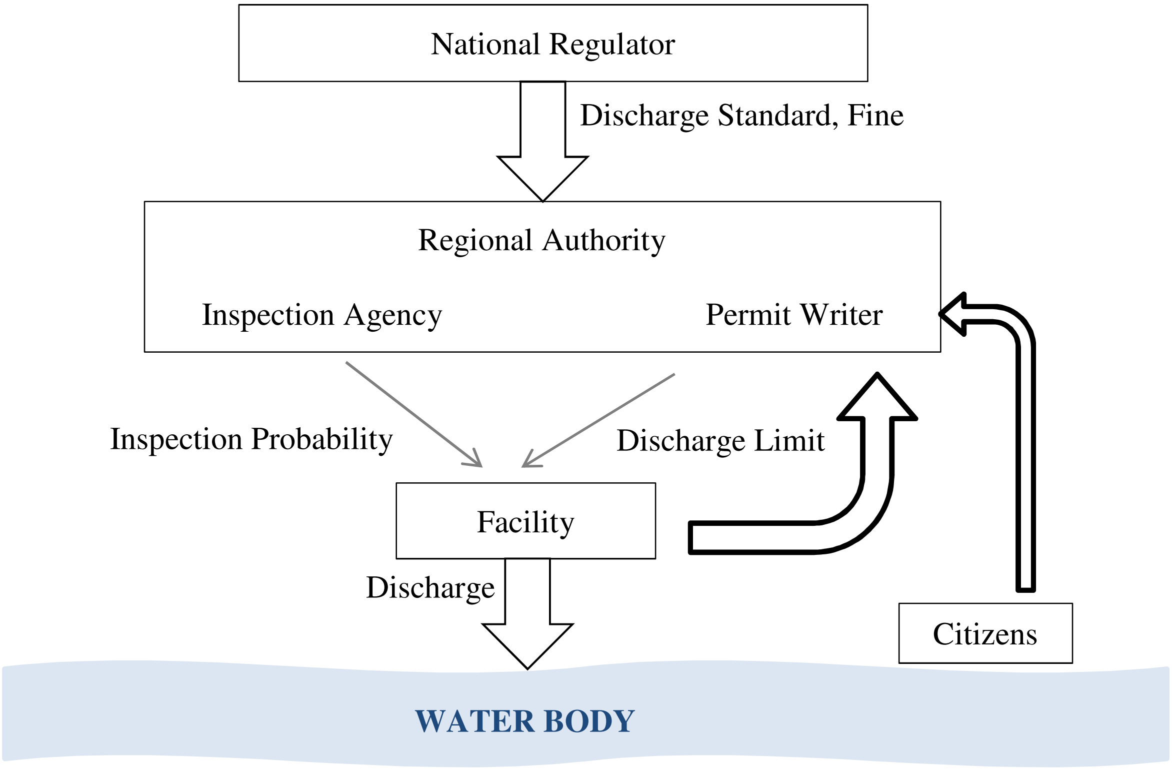

Figure 5

Timing of Decisions in the Extended Model with Negotiation