The Impact of Industry Structure and Penalty Policies on Incentives for Compliance and Regulatory Enforcement

Kelly Kristen Lear
Kelley School of Business, Indiana University

John W. Maxwell
Kelley School of Business, Indiana University

September, 1997

Abstract: Established penalty policies require consideration of a firm's ability to pay when setting fines for environmental violations. This paper examines the optimal penalty structure, taking into account financial constraints. Contrary to the existing literature which advocates setting fines as high as possible, we identify conditions under which the optimal fine is zero and regulating the industry is sub-optimal. We extend our analysis to consider the impact of a change in industry structure on the optimal fine, compliance and regulatory resource strategies. An increase in the number of firms in the industry may free up regulatory resources either by increasing equilibrium compliance or by reducing a firm's ability to pay below the level necessary for socially beneficial regulation. We show that regulatory enforcement that achieves partial compliance is not necessarily better than no regulation at all.

We would like to thank James Barnes, Eric Rasmusen, an anonymous referee, and participants at the Indiana University Business Economics and Public Policy Workshop for helpful comments. We also thank Jonathon Libber of the U.S. Environmental Protection Agency for his assistance. Lear gratefully acknowledges the U. S. Small Business Administration for financial support (Contract No. SBAHQ-95-C-0026). Direct correspondence to Kelly Lear at 1309 E. 10th Street, Bloomington, IN 47405; Tel. 812/855-9219; Email. klear@indiana.edu

1 Introduction

Recent spending for pollution abatement and control (PAC) in the U.S. suggests the costs of compliance with environmental regulations are rising. In 1993, U.S. business expenditures for PAC reached $60.3 billion (in constant 1987 dollars), up from $46.6 billion in 1987. During this period, business spending on pollution control grew faster than gross domestic product-4.4 percent compared with 2.1 percent (Rutledge and Vogan 1995, 39). The costs of pollution abatement and control provide firms with an incentive to violate environmental regulations, making enforcement essential. However, regulatory authorities face tight budget constraints on resources available for monitoring and enforcement. Portney (1990, 10) reports that between 1980 and 1989, the U.S. Environmental Protection Agency's (EPA) operating budget fell by roughly 15 percent in real terms. More recently, budget proposals threatened deep cuts in EPA programs, particularly in its spending on enforcement (Cushman 1995, A35). In addition, deterrence is further restricted if fines are limited to amounts firms can afford to pay. Given these constraints on available policy instruments, authorities seek strategies to assist them in allocating scarce resources and designing effective penalties.

This paper examines the effect of financial constraints and changes in industry structure, as defined by the number of firms in the industry, n, on enforcement and compliance decisions. We determine the optimal penalty structure, taking into account its impact on firm compliance and regulatory spending on monitoring and enforcement. Modeling the hierarchical structure of government enforcement, we show that when penalties are limited by a firm's ability to pay, the optimal fine is either the maximum amount the firm can afford to pay or zero. In the case where a zero fine is optimal, net social benefits are maximized by not regulating the industry. Expanding on the existing literature, we consider the impact of a change in industry structure on the optimal magnitude of the fine, the equilibrium probability of compliance and the level of regulatory resources. We identify two properties of the monitoring technology that influence the behavior of both firms and the regulatory agency in equilibrium: (1) the ease of monitoring and (2) the marginal return to regulatory resources.

The economic literature on enforcement stems from a seminal paper by Becker (1968) who proposed that the social loss from offenses could be minimized by the setting the fine as high as possible, and lowering resources accordingly, to maintain the same expected penalty. Polinsky and Shavell (1991) point out that the magnitude of the fine may be limited by wealth constraints. They show that when wealth varies across potential offenders, the optimal penalty is less than the wealth of the highest wealth individual since raising the fine and lowering the probability of detection reduces the level of deterrence for individuals who cannot afford to pay the fine. Other research relies on assumptions of risk-aversion (Polinsky and Shavell 1979) and erroneous monitoring (Bose 1995) to demonstrate that maximal fines are suboptimal.

Relaxing assumptions of variations in wealth, risk-aversion, and erroneous monitoring, we show that the optimal fine may be non-maximal when consideration is given to the firm's ability to pay the fine. Environmental legislation such as the EPA's civil penalty policy (EPA 1984) require that the size of the violator's business be considered when determining fines. Cohen (1992, 1080) reports that courts often do not impose penalties on firms that are bankrupt or have insufficient assets to pay the fine.

Taking into account the firm's financial constraints, we determine a range of fines and corresponding firm sizes, measured by profits, for which the optimal fine is zero and regulating the industry is not optimal. We define a "minimum effective fine for socially beneficial regulation," above which net social benefits are strictly increasing in the fine and at least equal to the level achieved prior to regulation. Fines below the "minimum effective fine" achieve low, or zero, levels of compliance and result in a level of net social benefits that is less than the unregulated level.

We employ a hierarchical model of enforcement, common in the literature on tax evasion, which distinguishes between a social planner (e.g., the government) and a regulator (e.g., the EPA) who differ in their objectives and control variables.[1] This distinction explicitly recognizes that although the regulator is under the control of the government, it may have its own agenda. The government establishes policy, then delegates the responsibilities of monitoring and enforcement to the regulatory agency. In the context of environmental regulation in the United States, Congress passes statutes that specify

[1]Hierarchical models are commonly used in the study of regulatory enforcement. See Cremer et al. (1990), Sanchez and Sobel (1993), and Bose (1995).

penalty maximums and the EPA is responsible for monitoring compliance and enforcing regulations within these guidelines.[2]

Consistent with the existing literature (Cremer et al. 1990; Bose 1995), we assume that the social planner maximizes net social benefits, while the regulator is minimizes the costs of monitoring and enforcement, net of penalty revenues. The assumed regulatory objective of cost minimization is designed to capt[illegible] the idea that regulators [illegible]ing ever increasing budgetary pressures. Moreover, F[illegible] of the Environmental Law Institute, Washington, D.C., states that existing federal EPA oversight of states' environmental protection programs places "more emphasis on administrative actions and capacity than on environmental quality" (Lepkowski 1995, 47).[3]

The three groups of players: a social planner, a regulator, and an industry of n firms, interact in a three stage game. In stage one, the social planner sets the fine to maximize the net social benefits of regulation. In stage two, the regulator determines the level of monitoring and enforcement resources that minimizes the costs of compliance, net of penalty revenues. [4] Simultaneously firms decide whether or not to comply with a costly emissions standard. In the final stage firms play a Cournot game given their compliance decision. Violators are fined F with probability p.

The model allows us to examine the impact of penalty policy on incentives facing the regulator and the industry, as well as the strategic interaction between these two parties. In addition to determining the optimal penalty structure, we extend the existing literature by examining how a change in the number of firms in the industry affects incentives facing firms and the regulator.

---

[2]For example, statutes such as the Clean Air Act (CAA), the Clean Water Act (CWA), the Resource Conservation and Recovery Act (RCRA), and the Safe Drinking Water Act (SDWA) specify penalty maximums.

[3]While other regulatory objectives are possible, such as maximizing compliance or the number of inspections, Cremer et al. (1990, 69) acknowledge that the issue of which is the most realistic remains a question for empirical research.

[4]In Garvie and Keeler (1994, 142) the regulator has "specific responsibility for monitoring firm compliance and taking enforcement actions to levy penalties against noncompliant firms." However, the regulator in their model does not set the penalty. Cremer et al. (1990) and Malik (1992) also present models in which penalties are pre-determined by a legislative body and the regulator is limited to determining the monitoring or audit frequency.

Recent studies present conflicting results regarding the impact of an increase in the number of firms on compliance. Garvie and Keeler (1994) examine how regulatory choice of monitoring and enforcement strategies affects incentives for compliance. We highlight their results regarding the impact of an increase in the number of firms on these incentives. Garvie and Keeler (1994, 150) show that when budgetary resources are limited, an increase in the number of firms lowers the optimal probability of monitoring. This reduces the expected penalty causing the level of compliance to decrease with an increase in the number of regulated firms. This analysis focuses on compliance costs, which are independent of the number of firms in the industry, and does not consider how an increase in the number of firms may affect firm profits and subsequently, the expected gain from non-compliance.

It is generally assumed that a crime is committed when the expected gain to the offender exceeds the expected penalty. Taking into account the impact of an increase in n on the expected gain from non-compliance, Chua et al. (1992) find that the equilibrium probability of compliance increases with the number of firms in the industry. This finding contradicts that of Garvie and Keeler (1994) and is somewhat counter-intuitive. The result is driven by the assumption of a fixed expected penalty. Under this assumption, an increase in the number of firms has no impact on the expected penalty. However, Chua et al. (1992) employ a Cournot model in which the expected gain from non-compliance falls as increased competition reduces profits earned by each firm. An increase in n therefore reduces the incentive to violate, while having no impact on the level of deterrence, and compliance increases in equilibrium.

One aim of this paper is to bridge the gap between these contradictory results. We allow both the probability of detection and the expected gain to fall with an increase in the number of firms in the industry. Consistent with existing models of regulatory enforcement (Stigler 1970; Polinsky and Shavell 1991; Malik 1990), we assume that the probability of being caught and fined, herein referred to as the probability of detection, p, is increasing in the amount of resources allocated to monitoring and enforcement, r. This relaxes the assumption of a fixed expected penalty assumed by Chua et al. (1992, 242) Furthermore, this paper is unique in that it endogenizes the effect of a change in the number of regulated firms, n, on the probability of detection. We explicitly model the probability of detection as decreasing in the number of firms in the industry, n. The probability of detection for any given firm is assumed to fall, ceteris paribus, with an increase in n as resources are spread across more firms. We denote the probability of detection as $p(r,n)$ with $p_n < 0$ and $p_r > 0$. Given $p_n < 0$, an increase in the number of regulated firms reduces both the expected gain from non-compliance and the expected penalty. We show how this dichotomy changes the incentives facing firms for non-compliance and subsequently affects the equilibrium probability of compliance.

First, we characterize the degree of monitoring difficulty. Monitoring difficulty varies across industries due to differences in the nature of the pollutants, the production processes, the centralization of sources, and the monitoring technology. In some industries, monitoring may be less resource intensive, involving drive-by surveillances of emissions opacity, inspection of pollution control equipment, or reviews of self-reported emissions levels. Russell, Harrington, and Vaughan (1986, 22) report that visual inspection are the "simplest, cheapest, and most common monitoring method." The electric utilities industry, for example, is relatively easy to monitor since large volumes of pollutants, such as sulfur dioxide and particulates, are released through centralized stack emissions. In addition, sources are required by the 1990 amendments to the Clean Air Act to install in-stack monitors for continuous emissions monitoring. EPA monitoring efforts involve checking reported emissions levels or using a remote sensing system (LIDAR) which registers plume emissions. In such industries, monitoring is relatively less resource intensive so the same amount of resources can be used rather easily to monitor an additional firm.

Other industries pose more of an enforcement challenge. Toxic pollutants are considerably more difficult to monitor than conventional pollutants due to the chemical testing which is required and the decentralization of sources (Viscusi, Vernon, and Harrington 1995, 740). Such industries include dry cleaners, gas stations, and bakeries. Emissions in these industries are decentralized and may occur during transportation, storage, or disposal. In addition, the nature of the production processes present opportunities for fugitive emissions which could occur at several different stages of the process. Monitoring is more resource intensive, making it difficult to monitor additional firms with the same amount of resources.

We define the degree of monitoring difficulty in terms of the properties of the monitoring technology. Monitoring is considered "difficult" when the probability of detection is rapidly declining in n so that the expected penalty falls faster than the expected gain from non-compliance. Monitoring is defined as "easy" when the probability of detection is slowly declining in n so that the expected penalty falls at a slower rate than the expected gain from non-compliance. Ceteris paribus, an increase in n reduces the probability of compliance when monitoring is difficult, but increases the probability of compliance when monitoring is easy. However, the impact of an increase in n on the equilibrium probability of compliance depends on the change in expected marginal penalty revenue.

The expected marginal penalty revenue is the marginal return to spending on monitoring and enforcement. An increase in n directly raises marginal penalty revenue which increases the optimal level of regulatory resources. However, an increase in n indirectly reduces marginal penalty revenue by lowering the probability of detection. This reduces the optimal level of resources. We show that the effect of an increase in n on resources and compliance in equilibrium is determined by the direction and magnitude of the change in marginal penalty revenue, as well as on the ease of monitoring.

Our results have implications for optimal penalty policies and provide valuable insights into firm and regulatory behavior. We show that net social benefits are not strictly increasing in the fine. As a result, the optimal fine is either the maximum amount the firm can afford to pay or zero. When the maximum effective fine for socially beneficial regulation exceeds the maximum fine the violator can afford to pay, a zero fine is optimal. By setting the fine equal to zero the social planner precludes ineffective regulatory spending on enforcement. In this case, penalty policies that restrict fines to affordable levels elicit costly regulatory spending on enforcement and private spending on compliance which exceed the benefit (if any) of reduced environmental damage.

We find that changes in industry structure have policy implications for the optimal penalty. An increase in the number of firms *lowers* each individual firm's ability to pay. However, this increase may simultaneously raise the minimum effective fine for socially beneficial regulation. As the two diverge, it will be no longer optimal to regulate the industry. Finally, we examine the impact of a change in industry structure on the equilibrium probability of compliance and level of regulatory resources is discussed with respect to the properties of the monitoring technology.

The remainder of this paper is organized as follows. In Section 2 we develop the three-stage game. In Section 3 we determine the optimal penalty structure. The effects of a change in the number of regulated firms on the equilibrium probability of compliance, the optimal resource allocation, and the optimal fine are examined in Section 4. We provide some concluding remarks in the final section.

2 The Model

We model the hierarchical structure of government enforcement to examine the interaction between firms and a regulatory agency. There are three groups of players: a social planner, a regulator, and an industry of n firms. The regulated industry is a Cournot oligopoly where firms produce a homogeneous good and incur a constant marginal cost of production c_0. Industry demand is $P(Q) = a - bQ$ where $Q = \sum_{i=1}^{n} q^i$ is total industry output and q^i is output of firm i for $i = 1, ..., n$. Pollution is a by-product of the production process and subject to a binding emissions standard. The standard is exogenously determined in a separate policy process which weighs the costs of environmental damage against the benefits of production.

As with the technology based standards of the Clean Water Act, firms must adopt a "cleaner" production process to comply with the standard.[5] Each firm i chooses its profit maximizing compliance probability $\alpha_i \in [0, 1]$, taking into account the expected strategies of the other firms, the regulator's resource allocation decision and the optimal fine. [6] Abatement increases the marginal cost of production from c_0 to c_1. We focus on continuing compliance and therefore treat the fixed costs of pollution control as sunk costs. The higher marginal cost of production under compliance provides firms with an incentive to violate. Violators are fined F with detection probability $p(r, n)$.

As outlined in the Introduction, the probability detection is a function of both the level

[5]The Clean Water Act imposes effluent limitations which require application of the best available technology (BAT) to priority pollutants listed in the National Resource Defense Council (NRDC) consent decree of 1976 and on additional toxic pollutants. "Conventional" pollutants [which include biological oxygen demand (BOD), suspended solids (SS), fecal coliform bacteria, acidity and alkalinity (pH), and grease and oil] are subject to the best conventional technology (BCT) effluent limitations (Arbuckle 1993, 172).

[6]This allows for the possibility of a mixed strategy which occurs if the firm is indifferent between complying and not complying, i.e., the expected gain from non-compliance equals the expected penalty.

of resources allocated by the regulator to monitoring and enforcement and the number of firms in the industry: $p(r,n) \in [0,1)$ for $r > 0$ and $p(0,n) = 0$.[7] Ceteris paribus, $p(r,n)$ is increasing in the level of monitoring resources, $p_r > 0$, with decreasing returns to spending on monitoring and enforcement, $p_{rr} < 0$ (Malik 1990, 343). Conversely, an increase in the number of firms lowers the probability of detection for a fixed level of resources such that $p_n < 0$ and $p_{nn} > 0$ to satisfy the non-negativity constraint on the probability function. We assume monitoring is error free; the probability of mistakenly fining a complying firm is zero.

We adopt a hierarchical enforcement structure where the regulatory agency is responsible for monitoring compliance and enforcing regulations that are predetermined by a social planner. As discussed earlier, the regulator and the social planner have different objectives. The social planner sets the fine to maximize the net social benefits of regulation. The regulator minimizes the costs of monitoring and enforcement, net of penalty revenues. The regulator's resource allocation, r, is its best response to the compliance strategy chosen by firms, α.

A summary of the order of play follows. In stage one, the social planner sets the fine for violations of the emission standard to maximize the net social benefits of regulation. In stage two, the cost minimizing regulator allocates resources to monitoring and enforcement. Symmetric firms simultaneously decide whether or not to comply with the binding emission standard.[8] In stage three, firms act as Cournot oligopolists and produce the profit maximizing level of output given their compliance decision. The regulator fines violators F with probability p. The game is solved below through backward induction to determine the sub-game perfect Nash Equilibria.

[7]We exclude $p(r,n) = 1$. For any n, there may exist a level of resources $r^*(n,F)$ which ensures that each firm in the industry will be monitored with probability one; however, it is unrealistic that such an endowment of regulatory resources will be appropriated given fiscal budget constraints. Garvie and Keeler (1994, 143) cite a number of authors who have addressed the severity of resource constraints facing environmental regulators [Melnick (1983), DiMento (1986), Hawkins (1984), Yeager (1991)].

[8]Bose (1995, 476) points out that simultaneous moves by the regulator and firms avoids the assumption of a credible commitment by the regulator to monitoring the industry and enforcing the regulation.

2.1 Stage 3: Output Market Equilibrium

Cournot oligopolists simultaneously choose the level of output, q_k^i, that maximizes expected profits, $E\pi_k$ where $k = 1$ if firm i chooses to comply with the emissions standard and incur the higher marginal costs c_1, or $k = 0$ if firm i chooses to violate the standard and incur the lower marginal costs c_0.[9] Industry demand is $P(Q) = a - bQ$ with $b > 0$ and $a > c_1 > c_0$. A representative firm's output decision is

$$\max_{q_k^i} E\pi_k^i = q_k^i[a - b(q_k^i + Eq^{-i})] - c_k q_k^i \; for \; k = 0, 1 \tag{1}$$

where Eq^{-i} represents the expected output of all other firms in the industry.

Firm i's reaction function in terms of the expected output level of all other firms is

$$q_k^i = (a - c_k - bEq^{-i})/2b. \tag{2}$$

Let $\hat{q}_k^i$ represent the Nash equilibrium level of output for firm i. The assumption of symmetry implies that $\hat{q}_k^i = \hat{q}_k$ for all i. Expected output for all other firms in the industry is

$$Eq^{-i} = \alpha^{-i}(n-1)\hat{q}_1 + (1-\alpha^{-i})(n-1)\hat{q}_o. \tag{3}$$

where α^{-i} represents the compliance strategy chosen by all other firms and $\alpha^{-i} \in [0, 1]$.

Solving Equations (2) and (3) simultaneously gives

$$Eq^{-i} = [\alpha^{-i}(n-1)(c_o - c_1) + (n-1)(a - c_o)]/b(n+1). \tag{4}$$

Substituting Equation (4) into (2) yields the symmetric Cournot-Nash equilibrium levels of output under non-compliance ($k = 0$) and compliance ($k = 1$), respectively

$$\hat{q}_o = [2(a - c_o) + \alpha^{-i}(n-1)(c_1 - c_o)]/(n+1)2b \tag{5}$$

$$\hat{q}_1 = [2(a - c_1) - (1-\alpha^{-i})(n-1)(c_1 - c_o)]/(n+1)2b. \tag{6}$$

These Nash equilibrium levels of output generate expected profits under non-compliance and compliance,

[9] As stated earlier, the fixed costs of pollution abatement are sunk and therefore do not influence the continuing compliance decision.

$$E\hat{\pi}_o(\alpha^{-i},n) = \frac{[2(a-c_o)+\alpha^{-i}(n-1)(c_1-c_0)]^2}{4b(n+1)^2} \tag{7}$$

$$E\hat{\pi}_1(\alpha^{-i},n) = \frac{[2(a-c_1)-(1-\alpha^{-i})(n-1)(c_1-c_0)]^2}{4b(n+1)^2}. \tag{8}$$

Let $E\hat{\delta}(\alpha^{-i},n) = E\hat{\pi}_0(\alpha^{-i},n) - E\hat{\pi}_1(\alpha^{-i},n)$ represent the expected gain from non-compliance which provides firms with an incentive to violate the regulation.

2.2 Stage 2: The Compliance and Regulatory Resource Allocation Decisions

Firm compliance and regulatory allocation of resources to monitoring and enforcement are determined simultaneously. A risk-neutral, representative firm chooses its compliance strategy, α_i, to maximize expected profits.

$$\max_{\alpha_i} \alpha_i E\hat{\pi}_1(\alpha^{-i},n) + (1-\alpha_i)[E\hat{\pi}_0(\alpha^{-i},n) - p(r,n)F]. \tag{9}$$

The firm's first order condition yields

$$p(r,n)F = E\hat{\pi}_0(\alpha^{-i},n) - E\hat{\pi}_1(\alpha^{-i},n) \tag{10}$$

or

$$p(r,n)F = E\hat{\delta}(\alpha^{-i},n). \tag{11}$$

Note, firm i's strategy drops out of Equation (11), as is common in mixed strategy derivations. For all other firms, $j \neq i$, the best compliance response to the regulator's resource allocation, r, is

$$\alpha_j(r;n,F) = \begin{cases} 0 & \text{if } r < r_0(n,F), \\ \frac{2b(n+1)}{(n-1)(c_1-c_0)^2}[p(r,n)F - E\hat{\delta}(0,n)] & \text{if } r_0(n,F) \leq r \leq r_1(n,F), \\ 1 & \text{if } r > r_1(n,F), \end{cases}$$

where r_k satisfies $p(r_k,n) = E\hat{\delta}(k,n)/F$ for $k = 0, 1$.

In a symmetric equilibrium $\alpha_i = \alpha_j$ for all i and j. Let $\alpha(r;n,F)$ denote each firm's best compliance response for a given n and F. For $r < r_0$, the expected gain, $E\hat{\delta}(0,n)$, exceeds the expected penalty, $p(r,n)F$, which provides firms with an incentive to violate the regulation. For each $r \in [r_0, r_1]$, firms comply with a unique mixing probability $\alpha(r; n, F)$ as defined above. For $r > r_1$, the expected penalty deters violations and universal compliance is achieved.

Given $p_r(r, n) > 0$, $r_0 < r_1$ and the equilibrium probability of compliance is strictly increasing over (r_0, r_1) as shown in figure 1. Ceteris paribus, an increase in the level of regulatory resources raises the expected penalty making non-compliance less profitable. As one would expect, changes in either the fine or the number of firms in the industry shift the reaction function. This is discussed in more detail in Section 3.

The regulator's objective is to choose the level of resources that minimizes the costs of compliance net of penalty revenues,

$$\min_r C_R = r - (1 - \alpha)np(r, n)F. \tag{12}$$

As mentioned in the Introduction, the regulator's concern with tight budget constraints manifests itself in a cost minimization objective. The regulator recognizes penalty revenues not only because of there cost-reducing effect if returned to the agency, but also because they serve, in part, as an indicator of the agency's activity and provide justification for its existence.[10]

Minimizing costs with respect to r yields the regulator's first order condition

$$(1 - \alpha)np_r(r, n)F = 1, \tag{13}$$

which requires that resources be set at the level that equates marginal penalty revenue with the marginal cost of an additional dollar spent on enforcement. The regulator's reaction function, $r(\alpha; n, F)$, satisfies this condition. Ceteris paribus, an increase in the probability of compliance reduces the expected marginal penalty revenue. The lower return to resources induces the regulator to decrease r such that $\frac{\partial r}{\partial \alpha} < 0$.

The first order condition implies the standard condition necessary to obtain an interior solution for r: $\alpha \in [0, 1)$. Full compliance is not a sustainable equilibrium since at $\alpha = 1$,

[10]One might argue that the regulator is also concerned with the cost of industry compliance or with environmental damage. In this case the regulator's objective function is $C_R = n\alpha(c_1q_1 - c_0q_0) + D(\alpha, n) + r - (1 - \alpha)np(r, n)F$. Including these terms, however, has no impact on the regulator's first order condition or any of the results that follow.

$r(1; n, F) = 0$ but $\alpha(0; n, F) = 0$. The Nash equilibrium strategies in Stage 2 are given by the intersection of the reaction functions in figure 1. We denote the equilibrium strategies as $\hat{\alpha}(n, F)$ and $\hat{r}(n, F)$.

2.3 Stage 1: The Social Planner's Problem

The social planner is concerned with maximizing the net social benefits of regulation. This includes welfare, $W(\hat{\alpha}(n, F), n)$ less the social cost of environmental damage, $D(\hat{\alpha}(n, F), n)$ and the regulatory cost of enforcement. We assume that environmental damage from pollution, D , is strictly increasing in the number of firms in the industry, $D_n > 0$, and strictly decreasing in the probability of firm compliance, $D_\alpha < 0$. The social planner's decision problem is[11]

$$\max_F NB(n, F) = W(\hat{\alpha}(n, F), n) - D(\hat{\alpha}(n, F), n) - \hat{r}(n, F) \tag{14}$$

where welfare is the sum of consumer and producer surplus,

$$\begin{aligned} W(\hat{\alpha}(n, F), n) &= \int_0^{\hat{Q}_T} (a - bQ)dQ - [\hat{\alpha}(n, F)nc_1q_1 + (1 - \hat{\alpha}(n, F))nc_0q_0] \\ &= [\hat{\alpha}nq_1 + (1 - \hat{\alpha})nq_0][a - \frac{b}{2}(\hat{\alpha}nq_1 + (1 - \hat{\alpha})nq_0)] \\ &\quad -\hat{\alpha}nc_1q_1 - (1 - \hat{\alpha})nc_0q_0. \end{aligned} \tag{15}$$

Maximizing Equation (14) with respect to F gives the first order condition

$$\frac{\partial NB}{\partial F} = \left(\frac{\partial W}{\partial \hat{\alpha}} - \frac{\partial D}{\partial \hat{\alpha}}\right)\frac{\partial \hat{\alpha}}{\partial F} - \frac{\partial \hat{r}}{\partial F} = 0 \tag{16}$$

where

$$\frac{\partial W}{\partial \hat{\alpha}} = n(q_1 - q_0)[a - b(\hat{\alpha}nq_1 + (1 - \hat{\alpha})nq_0)] - [c_1q_1 - c_0q_0]. \tag{17}$$

Given $\hat{q}_1 < \hat{q}_0$, welfare is decreasing in compliance, $\frac{\partial W}{\partial \hat{\alpha}} < 0$. Higher costs under compliance restrict output to the socially optimal level. This reduces both consumer and producer surplus, having a negative effect on net social benefits.

[11]Note that the social planner recognizes penalty revenues as a simple transfer from non-compliant firms to the regulator. Thus penalty revenues do not influence its objective function.

However, an increase in compliance simultaneously reduces environmental damage, $\frac{\partial D}{\partial \hat{\alpha}} < 0$, which has a positive impact on net social benefits. If the reduction in welfare exceeds the reduction in environmental damage, $\frac{\partial W}{\partial \hat{\alpha}} - \frac{\partial D}{\partial \hat{\alpha}} < 0$, additional compliance fails to increase net social benefits. In this case, additional compliance is not desired. While this is possible, it seems reasonable that compliance is desired, so that an increase in compliance does not reduce net social benefits, but rather raises net social benefits: $\frac{\partial W}{\partial \hat{\alpha}} - \frac{\partial D}{\partial \hat{\alpha}} > 0$. We focus on the latter case in the analysis that follows. The impact of an increase in F on net social benefits therefore depends on the response of $\hat{r}$ and $\hat{\alpha}$ in equilibrium. The social planner's first order condition implies that the optimal penalty equates the marginal net social benefit of compliance with the marginal cost of enforcement. We now determine the optimal penalty structure.

3 The Optimal Fine

We examine the effect of an increase in the fine on the probability of firm compliance and on the regulator's reaction function for an industry of n firms. An increase in the fine raises the expected penalty, $p(r, n)F$. This increases compliance, $\frac{\partial \alpha}{\partial F} > 0$, and shifts $\hat{\alpha}(r; n, F)$ down as illustrated in figure 2.[12] In addition, an increase in F raises marginal penalty revenue, $(1-\alpha)np_r(r,n)F$. The regulator's best response is to increase r, $\frac{\partial r}{\partial F} > 0$, so the regulator's reaction function rotates up [see figure 2].[13]

It is obvious from figure 2 that an increase in F raises the equilibrium probability of compliance, $\frac{\partial \hat{\alpha}}{\partial F} > 0$ along $\alpha(r; n, F) \in (0,1)$. However, for some range of F along $\alpha(r; n, F) = 0$, $\frac{\partial \hat{\alpha}}{\partial F} = 0$. Totally differentiating the first order conditions in Equations (11) and (13) and using Cramer's rule, we determine the equilibrium response of resources to an increase in the fine. The numerator in Equation (18) below reveals that the effect of an increase in F on $\hat{r}$ is ambiguous,

$$\frac{\partial \hat{r}}{\partial F} = \frac{p_r[(1-\alpha)n - nF(\frac{\partial \alpha}{\partial F})]}{nF[p_r(\frac{\partial \alpha}{\partial r}) - (1-\alpha)p_{rr}]}. \quad (18)$$

[12] It can be shown that the size of the shift increases with r via $p(r, n)$. Raising the fine is therefore more effective at increasing compliance when regulatory spending on monitoring and enforcement is high.

[13] The regulator's reaction function rotates up from $\alpha = 1$ where it is undefined. The higher the rate of diminishing returns (the higher p_{rr}), the smaller the magnitude of the rotation.

Using terminology coined by Garvie and Keeler (1994, 148), we identify the dichotomous effect of a change in the fine on expected marginal penalty revenue. First, a higher fine directly raises expected marginal penalty revenue by $p_r(1-\hat{\alpha})n$, producing a "penalty enhancing effect." This increases the equilibrium level of resources along $\alpha(r;n,F)=0$ since the fine, and corresponding level of resources, are still too low to induce compliance such that $\frac{\partial\hat{\alpha}}{\partial F}=0$. However, if firms respond to the higher fine by increasing compliance, $\frac{\partial\hat{\alpha}}{\partial F}>0$, marginal penalty revenue falls by $nFp_r(\frac{\partial\alpha}{\partial F})$. This "pollution mitigating effect" reduces the equilibrium level of resources. In this case, the sign of $\frac{\partial\hat{r}}{\partial F}$ is determined by the dominant effect. In the analysis that follows, we focus on the case where raising the fine along $\hat{\alpha}\in(0,1)$ induces compliance, so that $\frac{\partial\hat{\alpha}}{\partial F}>0$ and it is optimal for the regulator to reduce resources in equilibrium, $\frac{\partial\hat{r}}{\partial F}<0$.

Define $F_0(n)$ as the minimum fine for partial compliance in an industry of n firms. At F_0, the cost minimizing level of resources for an industry of n firms is $r_0(n,F_0)=r(0;n,F_0)$ which satisfies

$$F_0=\frac{E\hat{\delta}(0,n)}{p(r_0,n)}. \tag{19}$$

For $F\in[0,F_0)$, the penalty and the corresponding equilibrium level of resources, $\hat{r}\in[0,r_0)$, result in an expected penalty that is too low to elicit compliance and $\hat{\alpha}(r;n,F)=0$. Raising the fine within this range therefore fails to increase compliance such that $\frac{\partial\hat{\alpha}}{\partial F}=0$. However, within $[0,F_0)$, an increase in F raises marginal penalty revenue, to which regulator's best response is to increase resources, $\frac{\partial\hat{r}}{\partial F}$. This is represented by movement along the vertical segment of $\alpha(r;n,F)=0$ in figure 1. Regulatory spending increases with no benefits of increased compliance. Equation (16) indicates that net social benefits are strictly decreasing in F within this range, as depicted in figure 3.

For $F\geq F_0$, the fine and the regulator's corresponding resource allocation produce an expected penalty that succeeds at eliciting partial compliance. Within this range, an increase in the fine raises the equilibrium level of compliance, $\frac{\partial\hat{\alpha}}{\partial F}>0$. This is represented by movement along the upward sloping portion of the firm compliance reaction function, $\hat{\alpha}(r;n,F)\in(0,1)$ in figure 1. The equilibrium level of resources falls, provided compliance is sufficiently responsive to an increase in the fine such that $np_rF(\frac{\partial\alpha}{\partial F}) > p_r(1-\hat{\alpha})n$. Equation (16) reveals that with $\frac{\partial\hat{\alpha}}{\partial F} > 0$ and $\frac{\partial\hat{r}}{\partial F} < 0$, net social benefits are strictly increasing in $F \geq F_0$ as shown in figure 3.

Our findings contradict Becker's (1968) classic theory that net social benefits are strictly increasing in the magnitude of the penalty. We find that there exists a range of fines, $F \in (0, F_0)$, for which net social benefits are actually decreasing in F. Higher penalty revenues provide an incentive for ineffective spending on monitoring and enforcement. An increase in F within this range results in costly regulatory spending with no success at achieving compliance. More importantly, we show that there is a range of fines above F_0 for which net social benefits are increasing in F, but regulation is *still* not optimal.

Define $F_e(n)$ as the minimum effective fine for socially beneficial regulation in an industry of n firms. F_e satisfies the following condition

$$NB(n,0) = NB(n,F_e) \tag{20}$$

where

$$\alpha(r;n,0) = 0 \; and \; r(\alpha;n,0) = 0. \tag{21}$$

For $F \in (F_0, F_e]$, an increase in the fine raises net benefits; however, net benefits are still below the level achieved without regulation, at $F = 0$ and $NB(n,0)$. Within this range, the public and private costs of achieving partial compliance outweigh the benefit of reduced environmental damage causing net social benefits to fall. For $F > F_e$, an increase in F is effective at raising net social benefits above the level achieved without regulation. This is obvious in figure 3.

It would appear that Becker's (1968, 183) recommendation of setting the fine as high as possible and lowering resources accordingly still maximizes net social benefits, provided the offender can afford the fine. However, it is generally accepted in the literature that the magnitude of the fine is constrained by the offender's ability to pay. In this one period game, the maximum penalty firms can afford to pay is their profits from non-compliance, defined as

$$\bar{F}(n) = \pi_0(\hat{\alpha}(n,F),n). \tag{22}$$

The social planner's choice of F in equilibrium is therefore constrained by $\bar{F}(n)$. Taking financial constraints into consideration, we show that it is not always optimal to set the fine as high as possible as Becker (1968, 183) proposed.

Proposition 1 For an industry of n firms, the optimal fine is

$$\hat{F}(n) = \begin{cases} \bar{F}(n) & \text{if } F_e(n) \leq \bar{F}(n), \\ 0 & \text{if } F_e(n) > \bar{F}(n). \end{cases}$$

For $\hat{F}(n) = \bar{F}(n)$, net social benefits are maximized by allocating the cost minimizing level of resources $\hat{r}(n, \bar{F}) > 0$ to monitoring and enforcement. Compliance is maximized at $\hat{\alpha}(n, \bar{F}) \in (0, 1)$. Full compliance in not achievable. For $\hat{F}(n) = 0$, net social benefits are maximized at $NB(n, 0) > NB(n, \bar{F}(n))$. Regulating the industry is not optimal, $\hat{r}(n, 0) = 0$.

Proof. When the minimum effective fine is feasible, $F_e(n) \leq \bar{F}(n)$, the social planner sets the equilibrium fine equal to a firm's wealth, $\hat{F} = \bar{F}$, the regulator devotes $\hat{r}(n, \bar{F}) > 0$ to monitoring and enforcement and firms comply with probability $\hat{\alpha}(n, \bar{F}) \in (0, 1)$. Net benefits are maximized as shown in figure 3 at $NB(n, \bar{F}) = W(\hat{\alpha}(n, \bar{F})) - D(\hat{\alpha}(n, \bar{F})) - \hat{r}(n, \bar{F})$.[14] However, when firms cannot afford to pay the minimum effective fine, $F_e(n) > \bar{F}(n)$, setting the fine equal to a firm's wealth results in regulatory spending on enforcement, $\hat{r}(n, \bar{F}) > 0$, with little or no benefit from compliance. The additional costs of monitoring and enforcement, $\frac{\partial \hat{r}}{\partial F}$, and reduced welfare (if some compliance is achieved), $\frac{\partial W}{\partial \hat{\alpha}}(\frac{\partial \hat{\alpha}}{\partial F})$, outweigh the benefit of reduced environmental damage, $\frac{\partial D}{\partial \hat{\alpha}}(\frac{\partial \hat{\alpha}}{\partial F})$. As a result, net social benefits are lower with regulation than without regulation, $NB(n, \bar{F}) < NB(n, 0)$. The social planner therefore maximizes net social benefits by setting $\hat{F} = 0$ and the regulator devotes no resources to monitoring and enforcement. Q.E.D.

4 Industry Structure

In this section we consider how an exogenous change in the number of firms in the industry

[14]Fines greater than $\bar{F}$ are infeasible by assumption; however, net benefits are continue to increase for feasible fines greater than F_e.

affects firm compliance, as well as the regulator's resource allocation decision for an established penalty. We show that the effect of an increase in n on a firm's reaction function depends on the properties of the monitoring technology. An increase in the number of regulated firms reduces the probability of detection for any given firm which lowers the expected penalty, $p_n F < 0$. However, increased competition simultaneously reduces the expected gain from non-compliance, $\frac{\partial E\hat{\delta}}{\partial n} < 0$. The overall impact on the probability of firm compliance depends on which falls faster as the comparative statics indicate below,

$$\frac{\partial \alpha}{\partial n} = \frac{2b(n+1)}{(c_1 - c_0)(n-1)} \left(p_n F - \frac{\partial E\hat{\delta}}{\partial n} \right), \tag{23}$$

where

$$\frac{\partial E\hat{\delta}}{\partial n} = -\frac{(c_1 - c_0)[a - c_0 - \alpha^{-1}(c_1 - c_0)]}{b(n+1)^2} < 0. \tag{24}$$

Equation (23) reveals that $\frac{\partial \alpha}{\partial n} > 0$ when the probability of detection is slowly declining in n such that $|\frac{\partial E\hat{\delta}}{\partial n}| > |p_n F|$. We define monitoring in an industry with these characteristics as easy. Ceteris paribus, compliance increases with the number of regulated firms and $\alpha(r; n, F)$ shifts down, as it does when the fine increases, as illustrated in figure 4(a). Conversely, $\frac{\partial \alpha}{\partial n} < 0$ when the probability of detection is rapidly declining in n such that $|\frac{\partial E\hat{\delta}}{\partial n}| < |p_n F|$. Monitoring in this type of industry is defined as difficult. Ceteris paribus, compliance decreases and $\alpha(r; n, F)$ shifts up as shown in figure 4(b). Under these circumstances, compliance decreases unless additional resources are allocated to monitoring and enforcement.[15]

A change in industry size, in terms of an increase n, affects the regulator's resource allocation decision through its impact on marginal penalty revenue as shown below,

$$\frac{\partial r}{\partial n} = \frac{-(1-\alpha)F(p_r + np_{rn})}{(1-\alpha)Fnp_{rr}}. \tag{25}$$

Ceteris paribus, an increase in the number of regulated firms directly raises marginal penalty revenue by $(1-\alpha)Fp_r$, which increases the cost minimizing level of r. We call this

[15]Note, $p_{rn} < 0$ implies that the shift in $\alpha(r; n, F)$ is smaller at lower levels of regulatory resources.

the "penalty enhancing-industry size effect." Conversely, an increase in n lowers marginal penalty revenue through its impact on the probability of detection, $(1-\alpha)Fnp_{rn}$, where $p_{rn} < 0$. This is termed the "detection mitigating-industry size effect." Lower marginal penalty revenue reduces the cost minimizing level of r. The overall impact of an increase in n on the regulator's reaction function depends on which effect dominates.

When the penalty enhancing-industry size effect dominates, $p_r > n|p_{rn}|$, marginal revenue increases and the regulator's reaction function shifts up, $\frac{\partial r}{\partial n} > 0$. However, when the detection mitigating-industry size effect dominates, $p_r < n|p_{rn}|$, marginal revenue decreases and the regulator's reaction function shifts down, $\frac{\partial r}{\partial n} < 0$.

We now consider the equilibrium effects of an increase in the number of firms in the industry on the regulator's resource allocation and firm compliance for a given penalty. Totally differentiating the first order conditions in Equations (11) and (13) and applying Cramer's rule gives

$$\frac{\partial \hat{\alpha}}{\partial n} = \frac{(1-\hat{\alpha})F[(\frac{\partial \alpha}{\partial r})(p_r + np_{rn}) - (\frac{\partial \alpha}{\partial n})np_{rr}]}{nF[(\frac{\partial \alpha}{\partial r})p_r - (1-\alpha)p_{rr}]}, \tag{26}$$

$$\frac{\partial \hat{r}}{\partial n} = \frac{(1-\hat{\alpha})(p_r + np_{rn})F - np_r(\frac{\partial \alpha}{\partial n})F}{nF[p_r(\frac{\partial \alpha}{\partial r}) - (1-\hat{\alpha})p_{rr}]}. \tag{27}$$

Equations (26) and (27) indicate that equilibrium responses ultimately depend on the change in marginal penalty revenue, $p_r + np_{rn}$, and the ease of monitoring, $\frac{\partial \alpha}{\partial n}$.

For a given penalty, the equilibrium change in net social benefits with respect to n is

$$\frac{\partial NB(n,F)}{\partial n} = \left(\frac{\partial W}{\partial n} - \frac{\partial D}{\partial n}\right) + \left[\left(\frac{\partial W}{\partial \hat{\alpha}} - \frac{\partial D}{\partial \hat{\alpha}}\right)\frac{\partial \hat{\alpha}}{\partial n} - \frac{\partial \hat{r}}{\partial n}\right]. \tag{28}$$

The first term on the right hand side of Equation (28) represents the direct effect of an increase in n on net social benefits. This may be positive or negative since an increase in n raises welfare at the expense of greater environmental damage. If the direct effect is positive, the production benefits to consumers and producers offset the costs of greater environmental damage. Ceteris paribus, the net benefit function would shifts up, as illustrated in figure 5. Conversely, a negative direct effect shifts the net benefit function down in a similar fashion. [16] However, the second term on the right hand side indicates that an increase in n also impacts net benefits through the strategic behavior of firms and the regulator.[17] Since the aim of this paper is to study the strategic interaction between firms and the regulatory agency, we assume that the direct effect is small and focus on the strategic effect in the analysis that follows.

4.1 A Small Change in Marginal Penalty Revenue

Consider the case where a change in n produces in a small change in marginal penalty revenue such that the signs of $\frac{\partial \hat{\alpha}}{\partial n}$ and $\frac{\partial \hat{r}}{\partial n}$ are determined by ease of monitoring, $\frac{\partial \alpha}{\partial n}$. The equilibrium responses are presented in table 1 for shifts along $\alpha(r; n, F) \in (0, 1)$.

	Monitoring	
	Difficult	Easy
MR ↑	$\hat{\alpha}\downarrow, \hat{r}\uparrow$	$\hat{\alpha}\uparrow, \hat{r}\downarrow$
MR ↓	$\hat{\alpha}\downarrow, \hat{r}\uparrow$	$\hat{\alpha}\uparrow, \hat{r}\downarrow$
NB	NB ↓	NB ↑

Table 1: The Equilibrium Effect of an Increase in the Number of Firms for a Small Change in Marginal Revenue (MR)

Proposition 2 When the impact of an increase in the number of firms in an industry on marginal penalty revenue is small and monitoring is difficult ($|\frac{\partial E\hat{\delta}}{\partial n}| < |p_n F|$), the equilibrium probability of compliance is strictly decreasing in n and the equilibrium level of resources is strictly increasing in n. As a result, the net social benefit of regulation falls with an increase in n. Easy monitoring ($|\frac{\partial E\hat{\delta}}{\partial n}| > |p_n F|$) leads to correspondingly opposite results.

Proof. This proof is for difficult monitoring, the proof for easy monitoring is almost identical. When monitoring is difficult $\frac{\partial \alpha}{\partial n} < 0$. Given $p_{rr} < 0$, Equation (26) implies that $\frac{\partial \hat{\alpha}}{\partial n} < 0$. Conversely, $p_r > 0$ gives $\frac{\partial \hat{r}}{\partial n} > 0$ from Equation (27). An increases in n reduces the equilibrium probability of compliance, while raising the equilibrium level of regulatory resources. Equation (28) reveals that when the direct effect is small, net social benefits are strictly decreasing in n for $\frac{\partial \hat{\alpha}}{\partial n} < 0$ and $\frac{\partial \hat{r}}{\partial n} > 0$. Q.E.D.

[16] Note, we assume for simplicity that $\frac{\partial^2 NB}{\partial F\, \partial n} = 0$. The sign is, in fact, ambiguous.

[17] Recall, the coefficient on $\frac{\partial \hat{\alpha}}{\partial n}$ is assumed to be positive as discussed in Section 2.

The equilibrium impact of an increase in n on net benefits is illustrated in figure 5 for a small direct effect. In industries where monitoring is difficult, net social benefits decrease with an increase in n, as more resources are allocated to monitoring an industry where compliance has fallen. Assuming the strategic effect outweighs the direct effect, $NB(n, F)$ shifts down. Conversely, equilibrium net benefits are increasing in n under easy monitoring since an increase in n reduces the incentive for non-compliance and fewer resources are required for monitoring and enforcement. The positive strategic effect shifts $NB(n, F)$ up.[18]

It is important to note the impact of a change in industry structure on the optimal penalty. First, we examine the effect of an increase in n on the minimum fine for partial compliance. Totally differentiating Equation (19) and rewriting in terms of F_0 we find

$$\frac{\partial F_0}{\partial n} = \frac{p_r F_0}{p(r,n)} \left[\frac{(\frac{\partial E\hat{\delta}}{\partial n} - p_n F_0)}{F_0 p_r} - (\frac{\partial r}{\partial n}) \right]. \tag{29}$$

The first term in brackets represents the shift in $\alpha(r; n, F)$ with respect to n measured in terms of r, while the second term is the shift in $r(\alpha; n, F)$. When the shift in $r(\alpha; n, F)$ is smaller than the shift in $\alpha(r; n, F)$, as is the case when the change in marginal revenue is small, $\frac{\partial F_0}{\partial n}$ and r_0 are determined by the ease of monitoring. Under difficult monitoring, a higher fine is required to induce partial compliance, $\frac{\partial F_0}{\partial n} > 0$, and figure 4 indicates that r_0 increases, as well. The reverse is true when monitoring is easy, $\frac{\partial F_0}{\partial n} < 0$.[19]

Next, we consider how an increase in n affects a firm's ability to pay. Totally differentiating Equation (22) and arranging terms, we determine the equilibrium impact of an increase in n on $\bar{F}$,

[18]Note, equilibrium net benefits always decrease (increase) under difficult (easy) monitoring if the direct effect is negative (positive). However, there are two exceptions that arise when the direct effect is large. First, under difficult monitoring, a large, positive direct effect may offset the indirect effect causing net benefits to increase. Second, under easy monitoring, a large, negative direct effect may offset the positive strategic effect causing net benefits to fall. A large direct effect requires marginal net benefits from production by one additional firm to exceed the marginal change in firm compliance and regulatory spending.

[19]Equation (29) indicates that for difficult monitoring scenarios, the increase in F_0 is larger when marginal penalty revenue decreases, $\frac{\partial r}{\partial n} < 0$, than when marginal penalty revenue increases, $\frac{\partial r}{\partial n} > 0$. Again, the reverse is true when monitoring is easy.

$$\frac{\partial \bar{F}}{\partial n} = \frac{\partial E\pi_0(\hat{\alpha}, n)}{\partial n} + \left(\frac{\partial E\pi_0(\hat{\alpha}, n)}{\partial \hat{\alpha}}\right)\frac{\partial \hat{\alpha}}{\partial n}. \tag{30}$$

The direct impact of an increase in n is to reduce $\bar{F}$ since an increase in n reduces each firm's share of industry profits, $\frac{\partial E\bar{\pi}_0(\hat{\alpha},n)}{\partial n} < 0$. However, an increase in n also affects $\bar{F}$ indirectly through its impact on the equilibrium probability of compliance, as implied by the second term on the right hand side of Equation (30). An increase in compliance restricts output, which raises the equilibrium price and the expected profit from non-compliance, $\frac{\partial E\bar{\pi}_0(\hat{\alpha},n)}{\partial \hat{\alpha}} > 0$. When monitoring is easy, $\left(\frac{\partial \hat{\alpha}}{\partial n} > 0\right)$, the equilibrium probability of compliance increases with n. As a result, the indirect effect is positive and the overall change in $\bar{F}$ is ambiguous. However, when monitoring is difficult, $\left(\frac{\partial \hat{\alpha}}{\partial n} < 0\right)$, the equilibrium probability of compliance decreases with an increase in n. In this case, the indirect effect is negative and $\bar{F}$ falls, so $\left(\frac{\partial \bar{F}}{\partial n} < 0\right)$. This suggests that when monitoring is difficult, the minimum fine for partial compliance and the maximum affordable fine diverge, $\frac{\partial F_0}{\partial n} > 0$ while $\frac{\partial \bar{F}}{\partial n} < 0$. In addition, figure 5 reveals that the minimum effective fine also increases under difficult monitoring. Thus, an increase in n makes it more likely that regulating the industry is not optimal and the optimal fine is zero. Note, the minimum effective fine falls in industries where monitoring is easy.

4.2 A Large Change in Marginal Penalty Revenue

If a change in n produces a large change in marginal penalty revenue relative to the impact on firm compliance, the equilibrium effects are determined by the change in marginal penalty revenue, $(np_{rn} + p_r)$. Our results for this case are shown in table 2. Since each of these equilibria produce benefits of increased compliance or reduced regulatory spending at a cost (increased regulatory spending or reduced compliance, respectively), the equilibrium impact of an increase in n on net social benefits is ambiguous. We do not discuss these results in detail, however note that the sign of $\frac{\partial NB}{\partial n}$ depends on how much the social planner values compliance over regulatory saving. Equation (28) above indicates that increased compliance is valued more if the marginal social benefit of compliance, $(\frac{\partial W}{\partial n} - \frac{\partial D}{\partial n})\frac{\partial \hat{\alpha}}{\partial n}$, outweighs the marginal regulatory cost, $\frac{\partial f}{\partial n}$, and the direct effect of a change in net marginal welfare.

	Monitoring		Social Priority	
	Difficult	Easy	Compliance	Reg. Spending
MR $\uparrow$	$\hat{\alpha}\uparrow, \hat{r}\uparrow$	$\hat{\alpha}\uparrow, \hat{r}\uparrow$	$NB\uparrow$	$NB\downarrow$
MR $\downarrow$	$\hat{\alpha}\downarrow, \hat{r}\uparrow$	$\hat{\alpha}\uparrow, \hat{r}\downarrow$	$NB\downarrow$	$NB\uparrow$

Figure 2: The Equilibrium Effect of an Increase in the Number of Firms for a Large Change in Marginal Revenue (MR)

5 Conclusions

When penalty policies are restricted by a firm's ability to pay, setting fines at the maximum affordable level may actually reduce net social benefits below the level achieved prior to regulation. Penalty revenues from non-zero fines provide the regulator with an incentive to devote resources to monitoring and enforcement, even when the resulting level of deterrence is ineffective at achieving a socially beneficial level of compliance. This perverse regulatory incentive for ineffective enforcement is driven, in our model, by the concern with cost-minimization. This objective seems timely given the tight fiscal constraints facing regulatory agencies today. At zero or low levels of compliance, the higher public and private costs of regulation offset any benefit from reduced environmental damage. As a result, net social benefits decline. In this case, we find that in the optimal fine is zero and regulating the industry is not socially optimal.

In addition, this study extends the existing literature by examining the impact of a change in industry structure on optimal penalty policy, as well as on the interaction between compliance and regulatory strategies. The equilibrium probability of compliance may increase or decrease with an increase in the number of firms in the industry. An increase in the number of firms frees up regulatory resources by increasing the equilibrium probability of compliance in industries where monitoring is easy, provided the change in marginal penalty revenue is small. In addition, an increase in the number of firms may free up resources in industries where monitoring is difficult by reducing a firm's ability to pay and making it no longer optimal to regulate the industry.

References

[1] Arbuckle, J. Gordon 1993. "Water Pollution Control." In *Environmental Law Handbook, Twelfth Edition*, edited by Government Institutes Staff. Rockville, MD: 151-220.

[2] Becker, Gary S. 1968. "Crime and Punishment: An Economic Approach." *Journal of Political Economy* 76: 169-217.

[3] Bose, Pinaki 1995. "Regulatory Errors, Optimal Fines and the Level of Compliance." *Journal of Public Economics* 56: 475-484.

[4] Chua, Dale H., Peter W. Kennedy, and Benoit Laplante. 1992. "Industry Structure and Compliance with Environmental Standards." *Economics Letters* 40: 241-246.

[5] Cohen, Mark A. 1992. "Criminal Law, Environmental Crime and Punishment: Legal/Economic Theory and Empirical Evidence on Enforcement of Federal Environmental Statutes." *The Journal of Criminal Law and Criminology* 82: 1054-1108.

[6] Cremer, H., M. Marchand, P. Pesticau. 1990. "Evading, Auditing, and Taxing." *Journal of Public Economics* 43: 67-92.

[7] Cushman, John H. Jr. 1995. "Senate Backs Cuts in Environmental Spending." *New York Times* 15 December, sec. A, p. 35.

[8] DiMento, J. F. 1986. *Environmental Law and American Business.* New York: Plenum Press.

[9] Garvie, Devon and Andrew Keeler. 1994. "Incomplete Enforcement with Endogenous Regulatory Choice." *Journal of Public Economics* 55: 141-162.

[10] Hawkins, K. 1984. *Environment and Enforcement: Regulation and the Social Definition of Pollution.* Oxford: Clarendon Press.

[11] Lepkowski, Wil. 1995. "Delegating Authority: Government Seeks New Balance in Environmental Protection." *Chemical & Engineering News* 73(44): 44-49.

[12] Malik, Arun S. 1990. "Avoidance, Screening and Optimum Enforcement." *Rand Journal of Economics* 21(3): 341-353.

[13] Malik, Arun S. 1992. "Enforcement Costs and the Choice of Policy Instruments for Controlling Pollution." *Economic Inquiry* 30: 714-721.

[14] Melnick, R. S. 1983. *Regulation and the Courts: The Case of the Clean Air Act.* Washington, DC: Brookings Institutions.

[15] Polinsky, A. Mitchell and Steven Shavell. 1979. "The Optimal Tradeoff between the Probability and Magnitude of Fines." *American Economic Review* 69: 880-891.

[16] Polinsky, A. Mitchell and Steven Shavell. 1991. "A Note on Optimal Fines When Wealth Varies Among Individuals." *American Economic Review* 81: 618-621.

[17] Portney, Paul R. 1990. "Evolution of Federal Regulation." *Public Policies for Environmental Protection*, edited by Paul R. Portney. Washington, DC: Resources for the Future: 7-25.

[18] Russell, Clifford S., Winston Harrington, and W. J. Vaughan. 1986. *Enforcing Pollution Control Laws.* Washington, DC: Resources for the Future.

[19] Rutledge, G. L. and C. R. Vogan. 1995. "Pollution Abatement and Control Expenditures, 1993." *Survey of Current Business* 75: 36-45.

[20] Sanchez, Isabel and Joel Sobel. 1993. "Hierarchical Design and Enforcement of Income Tax Policies." *Journal of Public Economics* 50: 345-369.

[21] Stigler, George J. 1970. "The Optimum Enforcement of Laws." *Journal of Political Economy* 78: 526-536.

[22] U. S. Environmental Protection Agency. 1984. "Policy on Civil Penalties." *EPA General Enforcement Policy #GM-21.* Washington, DC: U.S. Environmental Protection Agency.

[23] U. S. Environmental Protection Agency. 1996. *Enforcement and Compliance Assurance Accomplishments Report FY 1995.* Washington, DC: U.S. Environmental Protection Agency, Office of Enforcement and Compliance Assurance.

[24] Viscusi, W. Kip, John M. Vernon, and Joseph E. Harrington, Jr. 1995. *Economics of Regulation and Antitrust.* Boston: MIT Press: 740-747.

[25] Yeager, P. C. 1991. *The Limits of Law: The Public Regulation of Private Pollution.* New York: Cambridge University Press.

Figure 1: Firm and Regulatory Reaction Functions

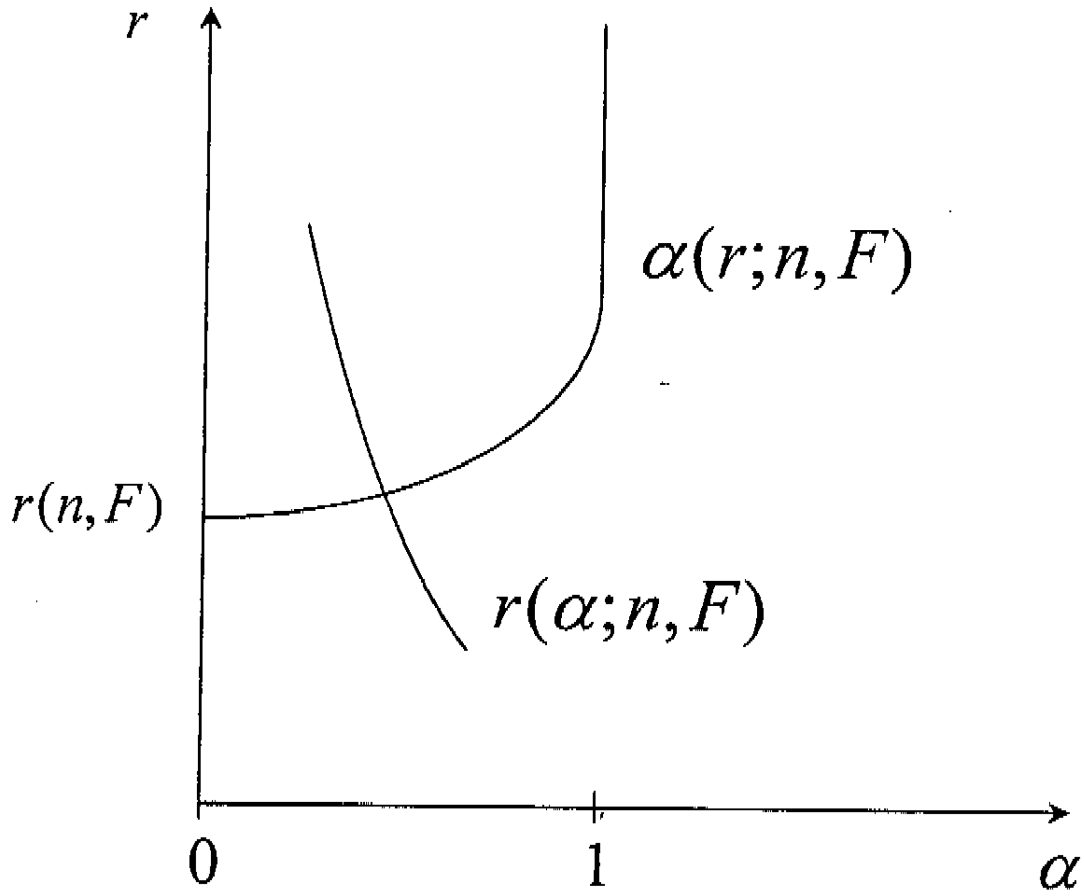


Figure 2: The Impact of an Increase in the Fine on the Reaction Functions

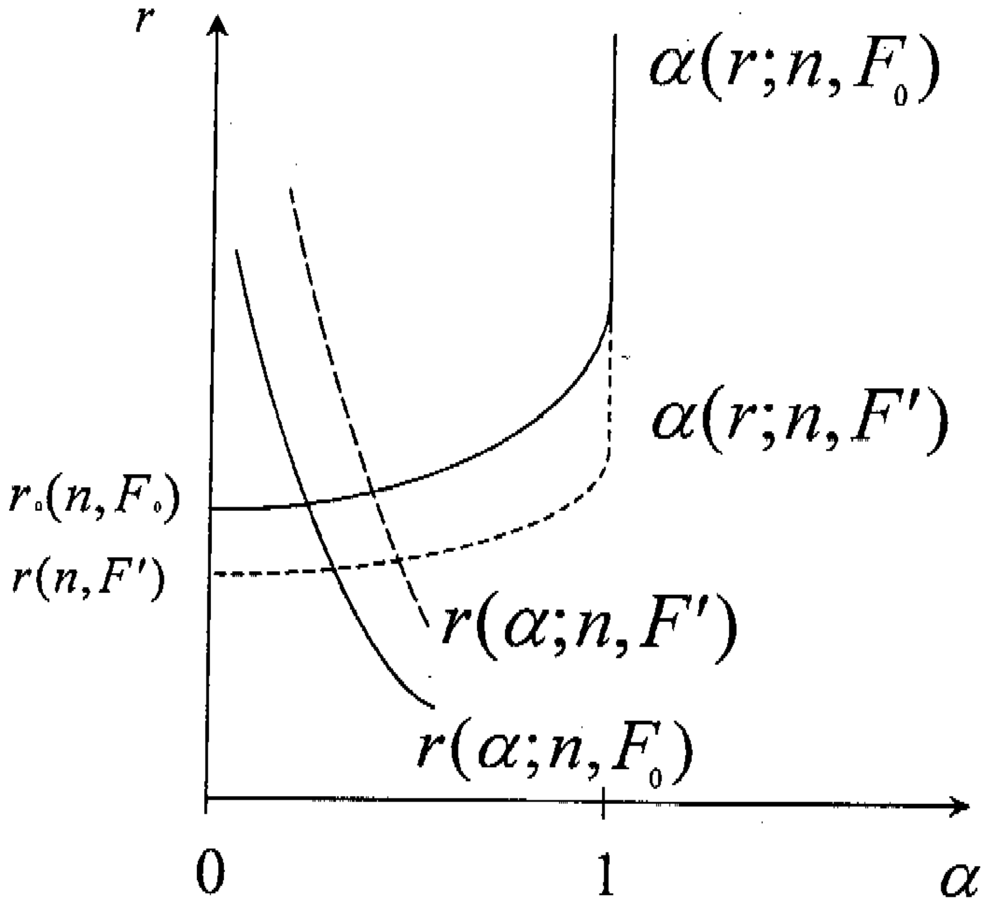


Figure 3: Net Social Benefits of Regulation

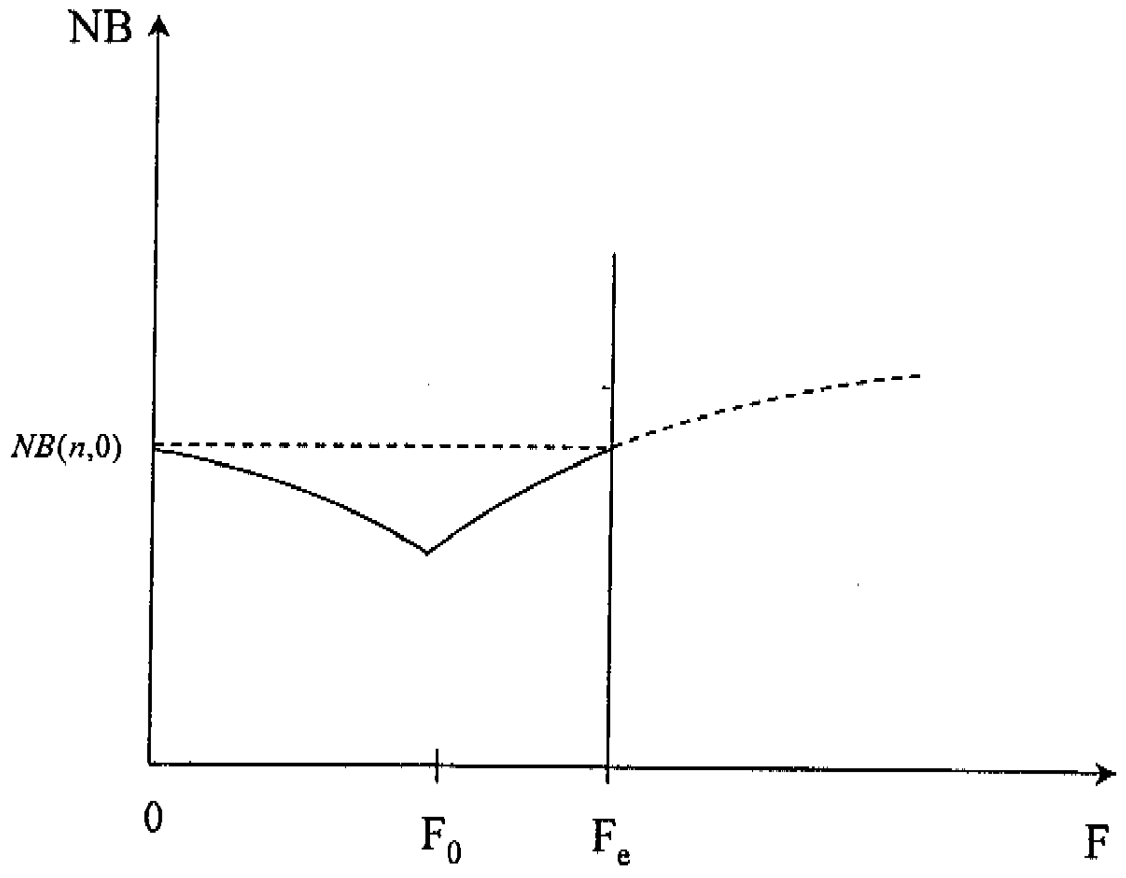
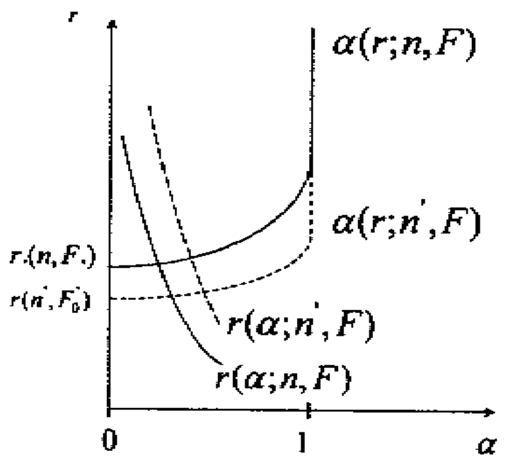


Figure 4

(a)

A Change in Industry Structure under Easy Monitoring



(b)

A Change in Industry Structure under Difficult Monitoring

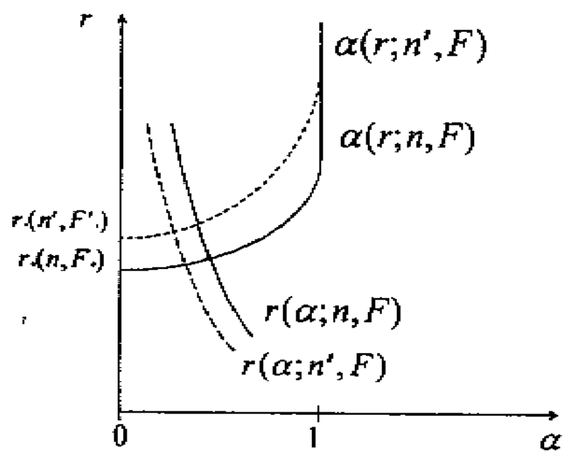


Figure 5: The Equilibrium Impact of a Change in Industry Structure on Net Social Benefits