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Monitoring Technology and Industry Structure: Firm Incentives to Comply with Environmental Regulations

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Abstract

As the rollback of EPA funding continues, tough decisions regarding the allocation of scarce monitoring resources have to be made. While it is clear that the EPA must place a high priority on monitoring the pollutants that cause the most harm to society, other factors must also be given careful consideration. This paper examines how industry structure (the number of firms) and monitoring technology influence firm incentives to violate a binding emissions standard. We show that the overall effect of a change in industry structure on the level of compliance depends on which falls faster: the expected penalty or the expected gain from non-compliance. We characterize our results in terms of the degree of monitoring difficulty and find that the equilibrium probability of compliance may be increasing or decreasing in the number of firms. Our results have several interesting policy implications. In numerical simulations we show that across the board cuts in enforcement programs are suboptimal. We define upper and lower bounds on the fine and show that in certain situations raising the fine is not feasible; the only way to increase compliance is by allocating more resources to enforcement. Finally, we find that when the regulator's objective is to maintain a target level of compliance, entry or exit of firms may free up regulatory resources depending on the ease of monitoring.

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, real U.S. business expenditures for PAC reached \$ 60.3 billion (in constant 1987 dollars), up from \$ 46.6 billion in 1987. During this period, spending on pollution control grew faster than gross domestic product-4.4 percent compared with 2.1 percent (Rutledge and Vogan, 1995, p. 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. Russell (1990) reports that between 1980 and 1989, EPA's operating budget fell by roughly 15 percent in real terms. More recent budget proposals threaten deep cuts in EPA programs, particularly in its spending on enforcement.[1] In this contractionary fiscal environment, regulatory agencies seek strategies to assist them in allocating scarce resources and administering budget cuts, while achieving the desired level of compliance. We identify three factors which influence this decision: (1) the ease of monitoring; (2) the industry structure (number of firms); and (3) the damage caused by the violation. We study the first two factors in this paper and consider the third in future research. In particular, we examine how firm incentives to violate an environmental regulation differ across industries in order to determine how resources should be allocated. In addition, we identify constraints on the magnitude of the fine which is imposed when firms are caught violating a regulation.

Much of the existing literature on compliance and enforcement examines the regulator's problem of determining the optimal enforcement policy separate from it's influence on firm behavior. However, few have integrated the two. In a paper which examines industry structure and firm behavior, Chua et al. (1992) find that the equilibrium probability of compliance is higher the larger the number of firms in the industry. The critical assumption for this result is that the probability of detection, p, is constant. We find fault with this assumption because it fails to consider how the probability changes with the level of monitoring and enforcement resources, r, or with the number of firms in the industry, n.

It is generally accepted that the probability of detection is determined by the amount

[1] *New York Times*, December 15, 1995.

of resources allocated to monitoring and enforcement (Becker, 1968; Stigler, 1970; Polinsky and Shavell, 1978, 1990, 1991; Malik, 1990). Similarly, we assume that the probability of detection is an increasing function of the level of resources devoted to monitoring and enforcement. Furthermore, this paper is unique in that it considers the effect of a change in the number of firms on the probability of detection. For a fixed enforcement budget, we assume that for any given firm, the probability of being caught violating the regulation decreases with an increase in n, as the same amount of resources are used to monitor more firms. Thus, we denote the probability of detection as $p(r, n)$ where $p_n < 0$ and $p_r > 0$. Relaxing the constant probability assumption, we show that the equilibrium probability of compliance may **increase or decrease** with an increase in the number of firms. The overall effect on the level of compliance depends on whether the expected penalty falls faster than the expected gain from non-compliance.

We consider our results in terms of the degree of monitoring difficulty. Monitoring difficulty varies across industries due to differences in several factors including 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 self-reported emissions levels. Russell, Harrington, and Vaughan (1986, p. 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 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 Lidar, a remote sensing system 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.

However, 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). Examples of firms in 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 poses the possibility of fugitive emissions which could leak out through several different stages of the process. Monitoring is more resource intensive, making it difficult to monitor additional firms with the same amount of resources.

In this paper, we measure the degree of monitoring difficulty by the responsiveness of p to a change in n for a given level of monitoring and enforcement resources. We define monitoring as difficult if the expected penalty falls faster than the expected gain from non-compliance. Monitoring is considered easy if the expected penalty falls at a slower rate than the expected gain from non-compliance. We find that when monitoring is difficult, the equilibrium probability of compliance is monotonically decreasing in n. Since firms are symmetric, this implies that larger firms are more likely to comply. However, when monitoring is easy, the equilibrium probability of compliance is monotonically increasing in n. In this case, smaller firms are more likely to comply. Our results have policy implications for the allocation of resources to enforcement across different industries and for the magnitude of the fine, F.

There are several papers in the enforcement literature that examine the optimal magnitude of the fine. In a seminal paper, Becker (1968) proposed that costs could be minimized by lowering the frequency (probability) of detection and raising the fine as high as possible, while maintaining the same expected penalty, pF. However, this approach fails to consider possible limitations on the magnitude of the fine. Polinsky and Shavell (1991) point out that for individuals, the magnitude of the fine is limited by wealth constraints. Lowering the probability and raising the fine in excess of what one can afford to pay actually lowers the level of deterrence. This finding applies to firms, as well. Cohen (1992) reports that courts often do not impose penalties on firms that are bankrupt or have insufficient assets to pay the fine. Moreover, the EPA's civil penalty policy dictates that the size of the violator's business should be considered when determining the fine (Silverman, 1990). Thus, the achievable degree of deterrence is restricted not only by scarce regulatory resources, but also by firm profits or size.

In this paper, we define the maximum feasible fine a firm can afford to pay as the maximum profits it can earn through non-compliance. We show that, like firm profits, the maximum feasible fine is monotonically decreasing in the number of firms in the industry. This suggests that the maximum feasible fine is lower for smaller firms. We also identify the minimum fine that achieves universal compliance. Our results indicate that when monitoring is easy, the minimum fine for full compliance decreases with an increase n. In this monitoring scenario, fines necessary to induce universal compliance are lower for smaller firms. However, when monitoring is difficult, the minimum fine is increasing in n. Thus, a potential problem in industries that are difficult to monitor is that the minimum fine for full compliance may exceed the maximum feasible fine a firm can afford to pay. In this situation, the **only way** to achieve full compliance is to raise the level of regulatory resources.

Our results provide valuable insights as to firm behavior and have several implications for the regulator's resource allocation decision. In a numerical simulation of the model, we show that across the board cuts in resources are suboptimal. Equal reductions in resources across industries have differential effects on compliance. We show that a better strategy is to administer bigger cuts in industries that are less sensitive to resource reduction, while making smaller, or perhaps no reductions in industries where resources are more detrimental. Moreover, we show that the regulator should take into account potential entry(exit) into(from) industries when designing the enforcement policy. Entry will actually free up resources in industries that are easier to monitor, while requiring more resources to maintain the same level of compliance in industries where monitoring is difficult.

The remainder of this paper is organized as follows. Section 2 develops the two-stage, game theoretical model of a Cournot oligopolists decision of whether or not to comply with a binding emissions standard. Section 3 examines the effect of a change in the number of firms in the industry on both the expected net gain from non-compliance and the level of industry compliance. Section 4 characterizes the Nash equilibria for expected net gains from non-compliance which rise or fall with an increase in n. In Section 5, we simulate the model to illustrate how industry structure (number of firms) and monitoring difficulty affect the regulator's choice of r and F. The final section provides some concluding remarks and identifies future research topics. Figures and Tables are located in the appendix.

2 The Model

We model the industry as an n firm Cournot oligopoly where firms produce a homogeneous good and incur a constant marginal cost of production c_o. Pollution is a by-product of the production process and subject to a binding emissions standard imposed by the regulator. As with standards based on emission levels achievable by the Best Available Technology (BAT) or the Best Demonstrated Technology (BDT), firms must adopt a "cleaner" production process to comply. Abatement increases the marginal cost of production from c_o to c_1. We assume that the fixed costs of abatement are sunk. The higher marginal cost of abatement deters firms from complying with the regulation. Industry demand is $P(Q) = a - bQ$ where $Q = \sum_{i=1}^{n} q_i$ is total industry output, q_i is output of firm i for $i = 1, ..., n$, $b > 0$, and $a > c_1 > c_o$.

The regulator allocates resources, r, to monitoring and enforcing the emissions standard. Firms caught violating the standard incur a fine, F. The fine and the amount of monitoring resources are exogenously determined by the regulator.[2] We examine a representative firm's incentive to violate the regulation in order to provide the regulator with some guidance in determining the magnitude of these weapons, r and F.

For any given firm, the probability of being caught violating the standard is p. As outlined in the Introduction, the probability of detection is assumed to be a function of both the level of resources budgeted by the regulatory agency for monitoring the industry, and the number of firms in the industry: $p(r, n) \in [0, 1]$ for $r > 0$ and $p(0, n) = 0$.[3] Consistent with previous economic models of enforcement (Becker, 1968; Stigler, 1970; Polinsky and Shavell, 1990, 1991; Malik, 1990), the level of resources devoted to monitoring determines the probability of detection. *Ceteris paribus*, $p(r, n)$ is increasing in the level of monitoring resources, $p_r > 0$. We assume decreasing marginal returns to expenditure on monitoring and enforcement, $p_{rr} < 0$, as in Malik (1990). However, holding the monitoring

[2] In the final section, we discuss adding a stage to examine the regulator's problem of determining the optimal choice of r and F which will depend on, among other things, the damage cause by the pollution by-product. In this paper, we focus on the interaction between industry profits and the effectiveness of monitoring efforts.

[3] Note, for any n, there may exist a level of resources $r^*(n)$ which ensures that each firm in the industry will be monitored with probability one; however, it is unlikely that such an endowment of regulatory resources will be appropriated given fiscal budget constraints. Moreover, monitoring with certainty may not be the regulator's optimal strategy.

budget fixed, an increase in the number of firms lowers the probability of any given firm being caught violating the standard, $p_n < 0$. The non-negativity constraint on p requires $p_{nn} < 0$.

The model is a two-stage game in which firms are the only players. In the first stage, the representative firm, i, chooses its strategy of compliance or non-compliance with the predetermined emissions standard. In the second stage, firm i behaves as a Cournot oligopolist. The game is solved by backward induction to determine the subgame perfect Nash equilibrium.

Stage 2: Output Market Equilibrium

Cournot oligopolists simultaneously choose the optimal level of output which maximizes expected profits, $E\pi_k^i$ 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. Firm i's problem is to

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

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

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

If we denote the Nash equilibrium level of output for firm i as $\hat{q}_k^i$, then the assumption of symmetry implies $\hat{q}_k^i = \hat{q}_k$ for all i.

Let $\hat{\alpha}$ represent the equilibrium probability of compliance. Expected output for all other firms is

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

Solving Equations (2) and (3) simultaneously gives

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

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

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

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

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

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

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

Stage 1: The Compliance Decision

In Stage 1, firm i chooses its strategy of compliance or non-compliance based on its expected level of equilibrium profits and the expected fine. Let $E\hat{\delta}$ represent the equilibrium expected gain from non-compliance, $E\hat{\delta} = E\hat{\pi}_0 - E\hat{\pi}_1$, and let $E\hat{\gamma}$ represent the equilibrium expected gain from non-compliance net of the expected fine, $E\hat{\gamma} = E\hat{\delta} - p(r, n)F$. Firm i's decision rule is

$$\hat{\alpha} = \begin{cases} 0 & \text{if } E\hat{\gamma} > 0, \\ \in (0,1) & \text{if } E\hat{\gamma} = 0, \\ 1 & \text{if } E\hat{\gamma} < 0. \end{cases}$$

Three possible Nash equilibria exist: two symmetric pure strategy equilibria (universal compliance, $\hat{\alpha} = 1$, and universal non-compliance, $\hat{\alpha} = 0$) and one mixed strategy equilibrium ($\hat{\alpha} \in (0, 1)$).

Equation (6) reveals that when all firms are expected to violate the regulation ($\hat{\alpha} = 0$), there exists an industry size, $n^* = \frac{2a - c_1 - c_o}{c_1 - c_o}$, in which non-compliance is so widespread that the equilibrium price is driven below the marginal costs of production under compliance, c_1, making it unprofitable for any firm to comply and produce output. Thus, for $n \geq n^*$, $\hat{q}_1|_{\hat{\alpha}=0} = 0$ and only firms that violate the regulation produce output. Equation (5) implies that non-compliance is always profitable, even when everyone else is expected to violate the regulation. Thus, $\hat{q}_o|_{\hat{\alpha}=0} > 0$ for all n. When all firms are expected to comply ($\hat{\alpha} = 1$), the equilibrium price is closer to the higher marginal cost of production under compliance, c_1, making it profitable for a firm to produce output under either strategy, for any number of firms in the industry.

3 The Expected Net Gain from Non-Compliance

Firm incentives to comply with the regulation depend on the expected net gain from non-compliance, as measured by the additional profits the representative firm expects to earn through non-compliance less the penalty it expects to pay if caught violating the regulation. An expected net loss from non-compliance encourages firms to comply with the binding regulation; however, zero or positive expected net gains provide little or no incentive for compliance, resulting in some degree of non-compliance. In this section, we examine how a change in the number of firms affect firm incentives to comply.

First, we determine how the expected gain from non-compliance changes with the number of firms in the industry. The expected gain is $E\gamma = E\hat{\pi}_1 - E\hat{\pi}_0$, which given Equations (5)-(8) we write as,

$$E\hat{\delta}(n, \hat{\alpha}) = \left(\frac{(c_1 - c_o)}{2}\right)\left(\frac{2(a - c_o) + 2(a - c_1) + (2\hat{\alpha} - 1)(n - 1)(c_1 - c_o)}{2b(n+1)}\right). \tag{9}$$

In Figure 1, the expected gain from non-compliance is graphed as a function of n under the two pure strategies of universal compliance ($\hat{\alpha} = 1$) and universal non-compliance ($\hat{\alpha} = 0$). The graph starts from n=1 where the monopolist's gain from non-compliance is $\frac{(c_1 - c_o)}{4b}[2a - c_1 - c_0]$.

Lemma 1 *As the number of firms increases, the expected gain from non-compliance falls faster, the lower the equilibrium probability of compliance.*

Proof. The slope of the expected gain function under each pure strategy is given below.

$$\frac{\partial(E\hat{\delta})}{\partial n}\Big|_{\hat{\alpha}=1} = -\frac{(c_1 - c_o)(a - c_1)}{b(n+1)^2} > -\frac{(c_1 - c_o)(a - c_o)}{b(n+1)^2} = \frac{\partial(E\hat{\delta})}{\partial n}\Big|_{\hat{\alpha}=0} \tag{10}$$

Q.E.D.

Lemma 1 implies that the gain from non-compliance is greater when all firms are expected to comply ($\hat{\alpha} = 1$) since a firm that violates the regulation earns a higher price than when no one complies ($\hat{\alpha} = 0$).

The expected net gain from non-compliance, $E\hat{\gamma}$, is the expected gain, $E\hat{\delta}$, less the expected penalty, $p(r,n)F$,

$$E\hat{\gamma} = \left[\frac{(c_1 - c_o)}{2}\left(\frac{2(a-c_o) + 2(a-c_1) + (2\alpha - 1)(n-1)(c_1 - c_o)}{2b(n+1)}\right)\right] - \Big[p(r,n)F\Big]. \quad (11)$$

We take the partial derivative of $E\hat{\gamma}$ with respect to n to consider the effect of a change in the number of firms on the expected net gain from non-compliance,

$$\frac{\partial(E\hat{\gamma})}{\partial n} = -\left[\frac{(c_1 - c_o)}{b(n+1)^2}[a - c_o - \hat{\alpha}(c_1 - c_o)]\right] - \Big[p_n F\Big]. \quad (12)$$

The first term on the right-hand-side of Equation (12) is the rate of change in the expected gain from non-compliance, $\frac{\partial E\hat{\delta}}{\partial n} < 0$. As new firms enter the industry, profits earned by each individual firm are diminished. However, expected profits under the non-compliance strategy fall faster than expected profits under the compliance strategy, causing the expected net gain from non-compliance to decline. The rate of change in the expected penalty, $\frac{\partial pF}{\partial n}$, is also decreasing in n since $p_n < 0$. *Ceteris paribus*, an increase in n lowers the probability of detection which increases the expected net gain from non-compliance. Thus, the sign on Equation (12) is indeterminate.

Proposition 1 *Ceteris paribus, if an increase in n causes the expected gain from non-compliance to fall slower (faster) than the expected penalty, then the expected net gain from non-compliance is increasing (decreasing) in n. If the expected gain from non-compliance and the expected penalty fall at the same rate as n increases, then the expected net gain from non-compliance is fixed with respect to n.*

Proof. Follows directly from Equation (12). Q.E.D.

The effect of a change in n on the expected net gain from non-compliance has implications for the level of industry compliance. Proposition 2 identifies the relationship between the rate of change in the expected net gain from non-compliance and the level of industry compliance.

Proposition 2 *Ceteris paribus, if the expected net gain from non-compliance is increasing (decreasing) in n, then the equilibrium probability of compliance, $\hat{\alpha}$, is lower (higher) the larger the number of firms. If the expected net gain from non-compliance does not change with n, the equilibrium probability of compliance is not affected by a change in the number of firms.*

Proof. To examine the effect of a change in the number of firms on the probability of compliance, α, we totally differentiate $E\hat{\gamma}$, and arrange terms to derive

$$\frac{\partial \hat{\alpha}}{\partial n} = \frac{2[a - c_o - \hat{\alpha}(c_1 - c_o)]}{(c_1 - c_o)(n-1)(n+1)} + \frac{2b(n+1)^2 p_n F}{(c_1 - c_o)^2 (n-1)(n+1)}. \tag{13}$$

Recall, F, r, and λ are exogenous, so $dF = dr = d\lambda = 0$. Solving Equation (12) for $p_n F$ and substituting it into Equation (13) gives $\frac{\partial \hat{\alpha}}{\partial n}$ in terms of the rate of change in the expected net gain from non-compliance,

$$\frac{\partial \hat{\alpha}}{\partial n} = -\frac{2b}{(c_1 - c_o)^2 (n-1)} \left(\frac{\partial E\hat{\gamma}}{\partial n} \right). \tag{14}$$

Q.E.D.

If the rate of change in the expected net gain from non-compliance decreases with an increase in n, $\frac{\partial E\hat{\gamma}}{\partial n} < 0$, then the equilibrium probability of compliance increases with n, for a given level of fixed monitoring resources. Although the fall in the expected penalty reduces the degree of deterrence, it does not fall as much as the expected gain from non-compliance. When the rate of change in the expected net gain from non-compliance increases with n, $\frac{\partial E\hat{\gamma}}{\partial n} > 0$, the equilibrium probability of compliance is lower for larger n. In this case, the expected penalty falls faster than the expected gain from non-compliance and the lower level of deterrence fails to elicit compliance.

In this section, we have shown how a change in the number of firms in the industry indirectly affects the level of industry of compliance through its impact on the expected net gain from non-compliance. In Section 4, we characterize the Nash equilibrium strategies for the two cases: increasing and decreasing net gains from non-compliance. For each case we illustrate the impact of an increase in the number of firms on industry compliance.[4]

4 Characterization of the Nash Equilibria

To characterize the Nash equilibria, we examine two industry scenarios in which the parameters (a, b, c_o, c_1) may differ, resulting in different profit levels and different expected gains from non-compliance. The distinguishing feature between the two industries is how the net gain from non-compliance changes with an increase in the number of firms. In Section 3, we showed that whether or not the net gain from non-compliance increases or decreases with n depends on the rate at which the expected penalty falls relative to the decline in the expected gain from non-compliance. We consider this relationship in terms of the degree of monitoring difficulty which determines the responsiveness of the probability of detection to an increase in n, $\frac{\partial p}{\partial n}$. We present the following definitions.

Definition: Monitoring is considered **difficult** if, ceteris paribus, the expected penalty falls faster than the expected gain from non-compliance ($|\frac{\partial pF}{\partial n}| > |\frac{\partial E\hat{\delta}}{\partial n}|$).

Definition: Monitoring is considered **easy** if, ceteris paribus, the expected penalty falls slower than the expected gain from non-compliance ($|\frac{\partial pF}{\partial n}| < |\frac{\partial E\hat{\delta}}{\partial n}|$).

4.1 Difficult Monitoring: Increasing Net Gains from Non-Compliance

$$\left(\frac{\partial E\hat{\gamma}}{\partial n} > 0; |\frac{\partial pF}{\partial n}| > |\frac{\partial E\hat{\delta}}{\partial n}|\right)$$

The Nash equilibrium strategy for this case is illustrated in Figure 2 which superimposes an expected penalty function for a given fine, F, on the graph of the expected gain functions

[4] Proposition 2 indicates that a third possible case exists in which a change in the number of firms does not change the expected net gain from non-compliance. This situation arises when the expected penalty and the expected gain from non-compliance fall at exactly the same rate as n increases. If the expected penalty exceeds the expected gain, there is a net loss from non-compliance and the Nash equilibrium strategy is universal compliance ($\hat{\alpha} = 1$) for any number of firms in the industry. However, if the expected gain exceeds the expected penalty, there is a net gain from non-compliance and universal non-compliance ($\hat{\alpha} = 0$) is the Nash equilibrium strategy for any number of firms in the industry. Finally, if the expected penalty equals the expected gain from non-compliance, the expected net gain from non-compliance is zero and mixing is the Nash equilibrium strategy for any number of firms in the industry. We mention this unlikely case for completeness, but do not present it in detail in Section 4.

introduced in Figure 1. For relatively small n, $n < \hat{n}_{\hat{\alpha}=1}$, the expected penalty exceeds the expected gain from non-compliance and universal compliance is the Nash equilibrium strategy. For $n \in [\hat{n}_{\hat{\alpha}=1}, \hat{n}_{\hat{\alpha}=0}]$, firms play a mixed strategy of $\hat{\alpha} \in (0,1)$ in equilibrium. For relatively large n, $n > \hat{n}_{\hat{\alpha}=0}$, the expected penalty is less than the expected gain from non-compliance and universal non-compliance is the Nash equilibrium strategy. Figure 3 illustrates the equilibrium expected net gain from non-compliance for this case.

Proposition 3 *When monitoring is difficult, the equilibrium probability of compliance is monotonically decreasing in the number of firms in the industry.*

Proof. In our Cournot model, non-compliance is more prevalent for a relatively large number of firms ($n > n_{\hat{\alpha}=0}$) where the expected net gain from non-compliance is greater. The decline in the expected penalty as n grows large provides sufficient incentive for firms to violate the regulation since the expected gain from non- compliance does not fall as rapidly. The assumption of symmetry implies that firm size decreases with an increase in n as industry profits are shared among a larger number of firms. Thus, relatively large firms are more likely to be in compliance when monitoring is difficult. Q.E.D.

4.2 Easy Monitoring: Decreasing Net Gains from Non-Compliance

$$\left(\frac{\partial E\hat{\gamma}}{\partial n} < 0; \left|\frac{\partial pF}{\partial n}\right| < \left|\frac{\partial E\hat{\delta}}{\partial n}\right|\right)$$

Figure 4 illustrates the Nash equilibria strategy for this case. For relatively small n, $n < \hat{n}_{\hat{\alpha}=0}$, the expected penalty is less than the expected gain from non-compliance. Monitoring is completely ineffective and the Nash equilibrium strategy is universal non-compliance. For $n \in [\hat{n}_{\hat{\alpha}=0}, \hat{n}_{\hat{\alpha}=1}]$, the equilibrium strategy is to mix, $\hat{\alpha} \in (0,1)$. For relatively large n, $n > \hat{n}_{\hat{\alpha}=1}$, the expected penalty exceeds the expected gain from non-compliance. Monitoring is completely effective and universal compliance is the Nash equilibrium strategy. The equilibrium expected net gain from non-compliance is presented in Figure 5.

Proposition 4 *When monitoring is easy, the equilibrium probability of compliance is monotonically increasing in the number of firms in the industry.*

Proof. In our model, when monitoring is easy, the net gain from non-compliance is greater for small $n < n_{\hat{\alpha}=0}$. Thus, non-compliance is more prevalent for relatively small sizes of the industry. The symmetry assumption implies that smaller firms are more likely to be in compliance. Compliance is higher for large n where the expected penalty provides sufficient deterrence given the smaller expected gains from non-compliance due to reduced profits. Q.E.D.

Having examined firm behavior under the two possible cases of increasing and decreasing net gains from non-compliance, we now consider the policy implications of our results in terms of the regulator's resource allocation decision. We include numerical simulations of the two industry scenarios to illustrate our theoretical results.

5 Enforcement Policy and Market Structure

We have shown that industry structure (the number of firms) and monitoring technology influences the level of compliance. We now consider these results in terms of their impact on the regulator's resource allocation decision.[5] We illustrate our findings in numerical simulations presented in Tables I-V.

5.1 Across the Board Cuts in Resources are Suboptimal

One strategy to achieve mandated budget reductions is across the board cuts in regulatory resources. In this section, we show that across the board cuts are not optimal because they have differential effects on the level of compliance across industries. A reduction in the level of monitoring and enforcement resources shifts the expected penalty function down in Figures 2 and 4 and increases the number of firms for which non-compliance is the Nash equilibrium strategy. However, an equal reduction in resources across different industries elicits different degrees of non-compliance. One might think that the impact of a resource reduction on the level of compliance would be more severe in industries that are difficult to monitor. However, this is not necessarily true. The effect of a reduction depends on the rate at which the expected net gain from non-compliance increases with a reduction in r, $\frac{\partial E\gamma}{\partial r}$.

[5] In this paper we are only concerned with how firm behavior influences the regulator's resource allocation decision and the level of the fine. We do not consider the regulator's ultimate problem of determining the optimal magnitudes of these weapons. Damage to environmental quality is another factor, besides firm behavior, which may influence this decision.

Table I presents the difficult and easy monitoring scenarios. In the difficult monitoring scenario, the expected penalty falls faster than the expected gain from non-compliance causing the net gain from non-compliance to increase with the number of firms in the industry. The industry of $n = 61$ firms is initially in full-compliance with $r = 5$ and $F = \$25,025$. The easy monitoring scenario is presented in the lower half of Table I. In this case, the expected penalty falls at a slower rate than the expected gain from non-compliance, causing the net gain from non-compliance to fall with an increase in n. This industry of $n = 19$ firms is initially in full-compliance with $r = 5$ and $F = \$15,700$. An equal reduction in resources of 0.01 across both industries elicits non-compliance from roughly 5 firms, or 8 percent, in the industry that is difficult to monitor, while enticing 19 firms, or 64 percent, to violate the regulation in the easy monitoring industry. These results are presented in Tables II. The impact of the resource reduction is more severe in the industry that is easy to monitor because the expected net gain from non-compliance increases at a faster rate in this industry as r is reduced, 0.0517 as compared with 0.0168.

If the regulator's objective, when faced with a resource reduction, is to maximize compliance, the optimal response from the regulator would be to make greater reductions in industries which are less sensitive to changes in the level of monitoring resources. In our simulation, the regulator's optimal response is to make the entire reduction of 0.02 in the industry which is difficult to monitor, while making no cuts in the industry where monitoring is easy. The effects of a 0.02 reduction in the difficult monitoring scenario are presented in Table III. The resource reduction results in 83 percent compliance in the difficult monitoring industry, while maintaining full-compliance in the easy monitoring industry.

5.2 Restrictions on the Magnitude of the Fine

Thus far, we have assumed that the fine remains fixed. However, the obvious response to counteract a budget cut is to raise the fine which would shift the expected penalty function up in Figures 2 and 4. The minimum fine which achieves full-compliance ($\hat{\alpha} = 1$) is given below as a function of n,

$$\underline{F} > \frac{(c_1 - c_o)}{p}\left[\frac{(2(a - c_o) + 2(a - c_1) + (n-1)(c_1 - c_o))}{2b(n+1)}\right]. \qquad (15)$$

The minimum fine is essentially that which, when multiplied by the probability of detection, attains an expected penalty greater than the maximum expected gain from non-compliance for an industry of n firms.[6] To analyze how the minimum fine for universal compliance changes with an increase in the number of firms, we take the derivative of $\underline{F}$ with respect to n,

$$\frac{\partial \underline{F}}{\partial n} = \left(\frac{\partial E\hat{\delta}}{\partial n} - p_n \underline{F}\right)\left(\frac{1}{p^2}\right). \tag{16}$$

Since both $\frac{\partial E\hat{\delta}}{\partial n}$ and $p_n F$ are negative, the sign of $\frac{\partial \underline{F}}{\partial n}$ will depend on whether monitoring in the industry is difficult or easy. When monitoring is difficult, $(|\frac{\partial pF}{\partial n}| > |\frac{\partial E\hat{\delta}}{\partial n}|)$, the minimum fine increases with the number of firms in the industry since the expected net gain from non-compliance is greater for larger n. The symmetry of the model suggests that when monitoring is difficult, fines should be higher, the smaller the firm. However, when monitoring is easy, $(|\frac{\partial pF}{\partial n}| < |\frac{\partial E\hat{\delta}}{\partial n}|)$, the minimum fine decreases with an increase in the number of firms. In this monitoring scenario, fines should be lower, the smaller the firm. These results are illustrated in Tables I - III which give the minimum fine for both industry scenario. Table IV shows that if resources are cut by 1.0 in the industry that is difficult to monitor, the fine must be raised to $F = \$26,693$ in order to maintain universal compliance.

Note, however, that simply raising the fine is not always a feasible solution.[7] Polinsky and Shavell (1991) have shown that for individuals the magnitude of the fine is limited to what offenders can afford to pay. In our one period game, the maximum amount a firm can afford to pay is it's one period profits under the non-compliance strategy. The highest achievable level of profits is earned by a firm who violates the regulation, given all other firms are expected to comply ($\hat{\alpha} = 1$).

Definition: The maximum feasible fine for an industry of n firms is

$$\bar{F} = E\hat{\pi}_o|_{(n,\alpha=1)} = \frac{[2(a - c_o) + (n-1)(c_1 - c_o)]^2}{4b(n+1)^2}. \tag{17}$$

[6] The maximum expected gain from non-compliance occurs when all other firms are expected to comply, thus Equation (15) is essentially $\underline{F} > \frac{1}{p}(E\hat{\delta}|_{\hat{\alpha}=1})$.

[7] In fact, given that raising the fine is less resource intensive, it is likely that the fine may already equal the maximum feasible fine, as defined in Equation (17).

Fines in excess of $\bar{F}$ provide no additional deterrence since firms cannot afford to pay the fine.

Proposition 5 *The maximum feasible fine is decreasing in the marginal costs of production under non-compliance, $\frac{\partial \bar{F}}{\partial c_o} < 0$, and increasing in the marginal costs of production under compliance, $\frac{\partial \bar{F}}{\partial c_1} > 0$.*

Proof. Follows directly from differentiation of Equation (17). Q.E.D.

An increase in c_o reduces profits for the firm that violates the regulation, thus lowering the fine it can afford to pay. However, given the maximum profits under non- compliance are earned when all other firms are expected to comply ($\hat{\alpha} = 1$), an increase in c_1 reduces industry supply and drives up the equilibrium price. The firm that violates the regulation therefore earns higher profits and can afford to pay a higher fine. As expected, $\bar{F}$ is decreasing in n ($\frac{\partial \bar{F}}{\partial n} < 0$) in both industry scenarios, since firm profits decline with an increase in n, reducing the feasible amount which may be recovered. Thus, for any industry, the maximum feasible fine should be lower the smaller the size (profits) of the firms in the industry. This presents a potential problem in industries where monitoring is difficult.

We have shown that when monitoring is difficult the minimum fine increases with n. At the same time, the maximum fine is decreasing in n. Thus, a situation could arise for relatively small firms where the minimum fine for full-compliance exceeds the maximum feasible fine the firm can afford to pay. Table V provides an example of this. If resources are cut from $r = 5$ to $r = 4$, the minimum fine for full-compliance is \$26,693 which exceeds the maximum fine the firm can afford to pay, $\bar{F} = E\pi_0|_{\hat{\alpha}=1} = \$26,312$. Under these circumstances, the only way to achieve full compliance is to raise the level of resources devoted to monitoring and enforcement.

5.3 Entry/Exit and the Regulator's Resource Allocation Strategy

Our results in Section 3 also have implications for the regulator's resource allocation decision vis-a-vis long term budget planning. That is, entry or exit in an industry will have a differential impact on resource requirements across industries. We have shown that when monitoring is easy, compliance increases with the number of firms in the industry.

Thus, if the regulator's objective is to maintain a target level of compliance, an increase in n in such industries will free up monitoring resources. Conversely, we have shown that the level of compliance decreases with an increase in n when monitoring is difficult. In these industries, more resources are required to maintain the same level of compliance as new firms enter. This is illustrated in Table V. When the number of firms increases from 61 to 62 in the difficult monitoring industry, resources must be raised by 0.002 to maintain universal compliance at $n^* = 62$. However, when the number of firms in the easy monitoring industry increases from 19 to 20, resources can be reduced by 0.004 while still maintaining universal compliance. Resources can thereby be shifted from the easy monitoring industry to the difficult monitoring industry. In our example, more than enough resources are freed up to maintain full-compliance in the industry that is difficult to monitor.

This result suggests that the regulator must take into consideration the potential for entry or exit and it's affect on the level of industry compliance when budgeting resources for monitoring and enforcement. Resources can be shifted from easy monitoring industries where entry is expected, to difficult monitoring industries where entry is anticipated. Conversely, if firms are expected to exit certain industries, resources can be shifted from ones that are difficult to monitor to those that are easy to monitor.

6 Concluding Remarks

In this paper, we examined firm incentives to violate an environmental regulations when compliance is costly. Our analysis revealed that monitoring technology and industry structure play important roles in determining the level of compliance. Previous papers on compliance assume the probability of detection for any given firm is constant (Chua, 1992). Under this assumption the equilibrium probability of compliance is higher, the greater the number of firms in the industry. In this paper, we recognized that the probability of detection for any given firm is likely to be a function of level of resources devoted to monitoring and enforcement, as well as the number of firms in the industry. We assumed that for a given level of resources, the probability of monitoring falls with an increase in n as the same amount of resources are used to monitor more firms. For a given fine, a decline in the probability of detection reduces the expected penalty and lowers the level of deterrence. However, at the same time, an increase in the number of firms reduces firm profits and lowers the gain firms expect to earn from non-compliance. Thus, the overall impact of an increase in the number of firms on the net gain from non-compliance depends on which falls faster: the expected penalty or the expected gain from non-compliance. We considered the rate at which the expected penalty falls relative to the rate at which the expected gain declines in terms of monitoring difficulty.

Monitoring difficulty varies across industries due to differences in monitoring technologies, production processes, and the nature of the pollutants. To characterize this, we defined monitoring as difficult if the expected penalty falls faster than the expected gain from non-compliance. If the reverse hold true, we considered monitoring easy. We showed that when monitoring of an industry is difficult, the equilibrium probability of compliance is lower the larger the number of firms in the industry. The symmetry of the model implies that in this case, large firms are more likely to comply with the regulation. However, when monitoring is easy, the equilibrium probability of compliance is higher the larger the number of firm, implying small firms are more likely to comply.

Our finding that the degree of monitoring difficulty and industry structure (number of firms) affect the level of compliance provides several insights as to how monitoring resources should be allocated. In numerical simulations, we showed that across the board budget cuts as a means of achieving mandated budget reductions are suboptimal. An equal reduction in monitoring resources across industries elicits different degrees of non-compliance. If the regulator's objective is to maximize compliance, a better strategy is to make greater reduction in industries which are less sensitive to resource reduction, while making smaller, or even no reductions in industries that are more sensitive to changes in the level of monitoring resources. Furthermore, we showed that raising the fine is a means of offsetting non-compliance elicited by resource reductions; however, this may not always be possible. We showed that there exists a maximum feasible fine the firm can afford to pay. This maximum is lower the smaller the size of the firm. Fines in excess of the maximum provide no additional deterrence as they will not be recovered. In addition, we identified a minimum fine which induces universal compliance. We showed that in some industries, the minimum fine is increasing in n suggesting that smaller firms require a higher fine to induce universal compliance. Thus, a situation may arise where the minimum fine exceeds the maximum feasible fine. In this case, the only way to increase compliance is to raise the level of monitoring and enforcement resources devoted to this industry. Finally, we showed that the regulator should take into account the possibility of entry or exit into industries to more efficiently allocate resources.

In this paper, we focused on the impact of industry structure and monitoring difficulty on firm incentives to comply in order to provide the regulator with some insights for allocating of monitoring and enforcement resources and setting the fine. In future work, we will build on these results to formalize the regulator's problem of choosing these weapons, r and F, optimally. To do this, we will consider the damage to environmental quality imposed by the violation. In addition, we will conduct empirical research to examine factors, such as firm size, which may influence penalties levied by regulatory agencies such as the Environmental Protection Agency.

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Appendix: Figures and Tables

Figure 1: Expected Gains from Non-Compliance Under Both Pure Strategies

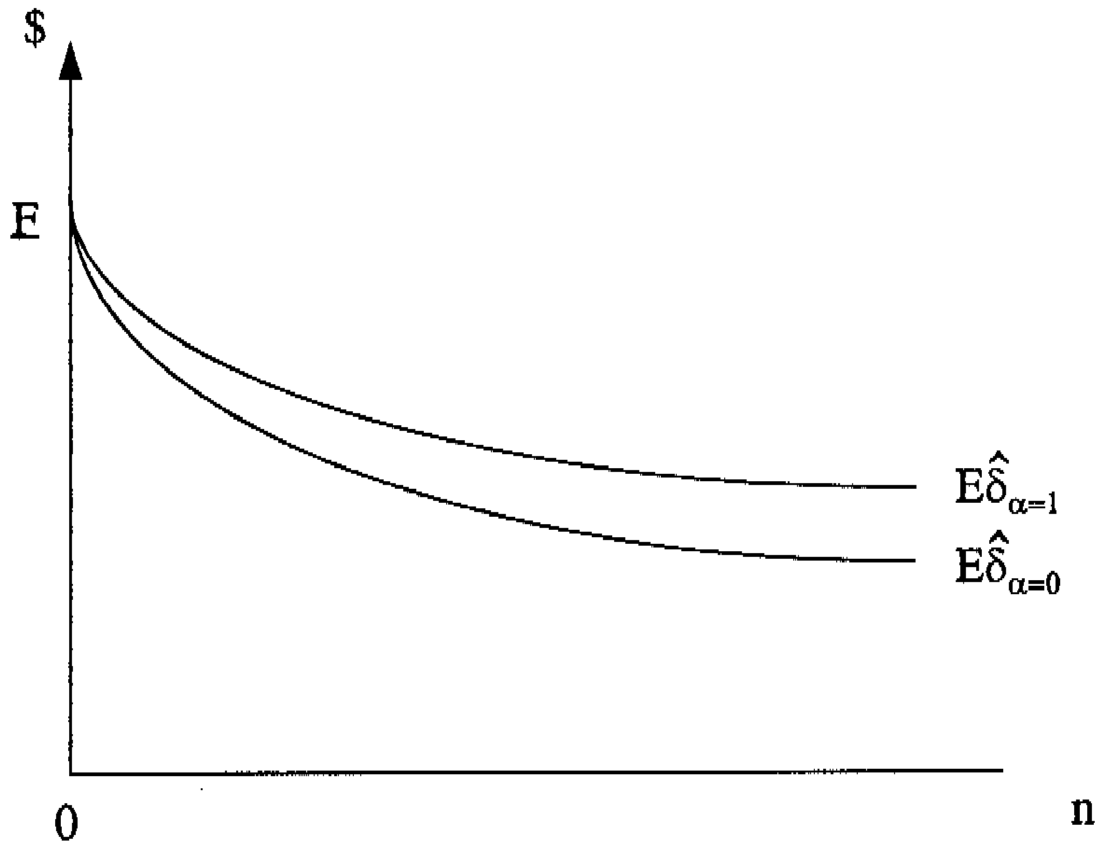

Figure 2: Difficult Monitoring

$$\left|\frac{\partial\, E\hat{\gamma}}{\partial\, n}\right| > 0;\left|\frac{\partial\, pF}{\partial\, n}\right| > \left|\frac{\partial\, E\hat{\delta}}{\partial\, n}\right|$$

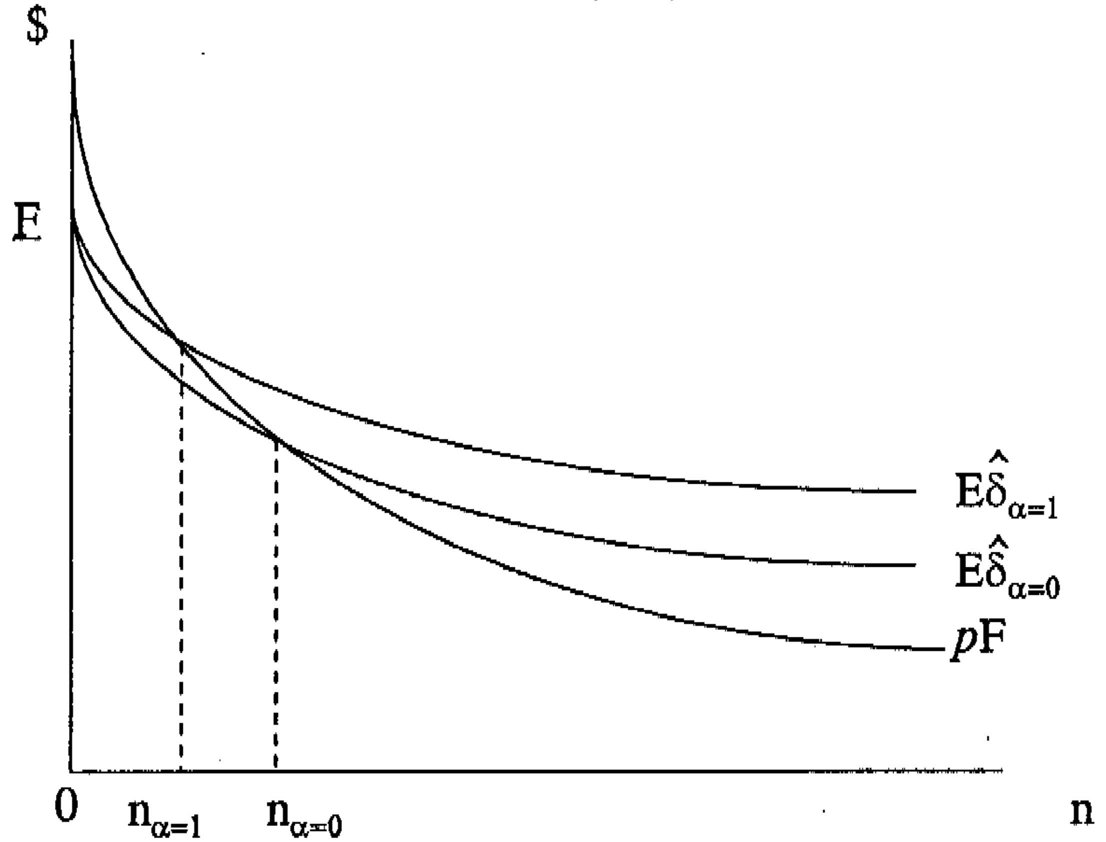

Figure 3: Increasing Expected Net Gains from Non-Compliance

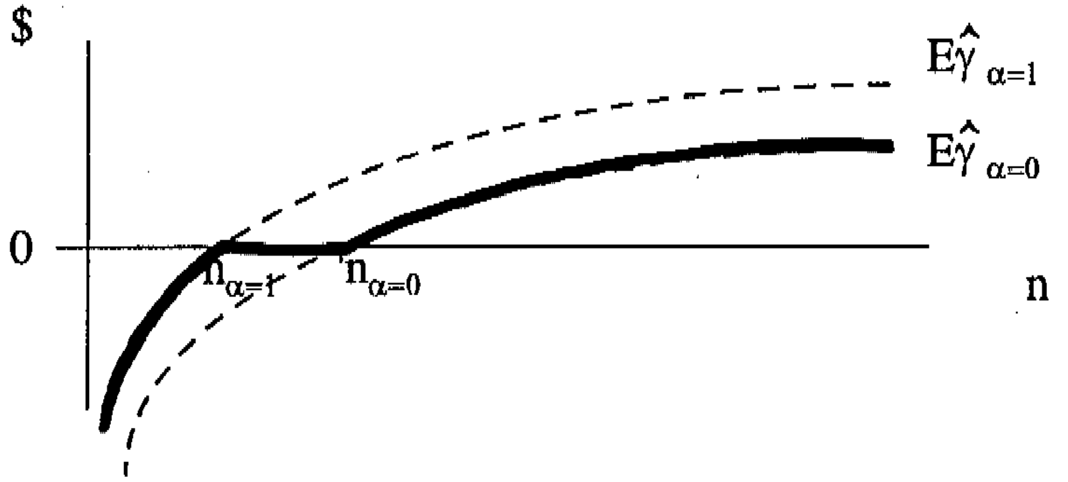

Figure 4: Easy Monitoring

$$\left|\frac{\partial\ E\hat{\gamma}}{\partial\ n}\right| < 0\,;\left|\frac{\partial\ pF}{\partial\ n}\right| < \left|\frac{\partial\ E\hat{\delta}}{\partial\ n}\right|$$

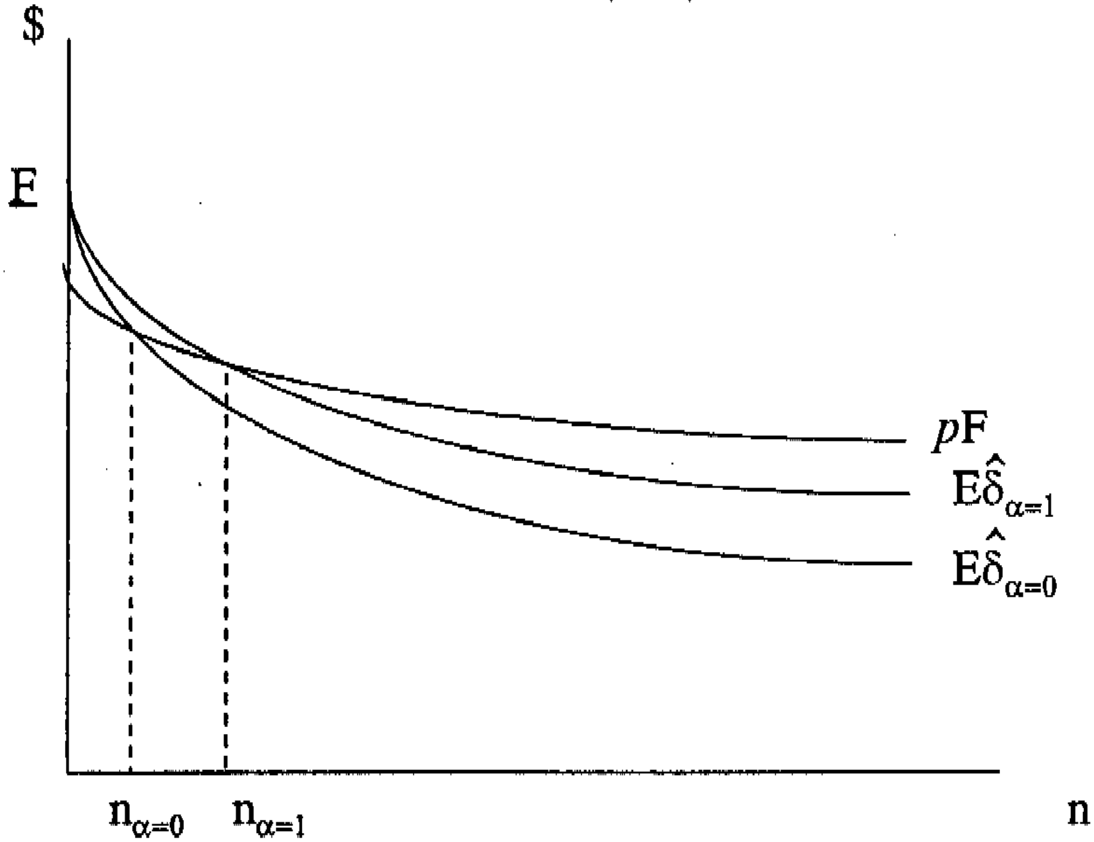

Figure 5: Decreasing Expected Net Gains from Non-Compliance

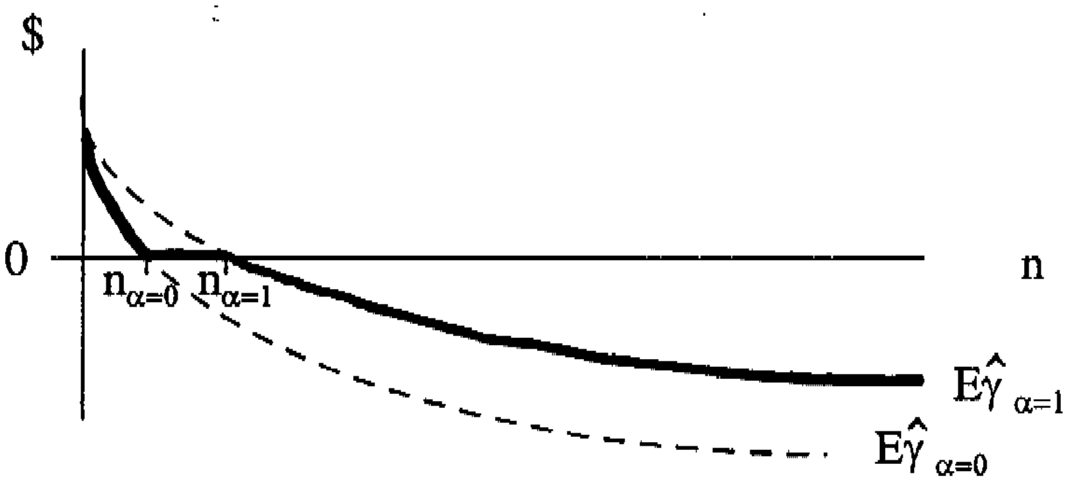

Table I: Initial Equilibrium

Industry Structure

Difficult Monitoring		Easy Monitoring	
a =	10,000	a =	10,000
b =	1	b =	0.8
c_0 =	3	c_0 =	6
c_1 =	5	c_1 =	7
α =	1	α =	1
r =	5	r =	5
F =	25,025	F =	15,700
p(r, n) =	$(1-1/r)(1/(n+.9))$	p(r, n) =	$(1-1/r)(1/(n+1.1))$

Difficult Monitoring: Increasing Net Gains from Non-Compliance

n =	1	20	40	**61**	80
$E\pi_0$ =	$ 24,985,002	$ 227,484	$ 59,917	**$ 26,312**	$ 15,474
$E\pi_1$ =	24,975,006	226,531	59,429	**25,989**	15,226
$E\delta$ =	9,996	953	489	**323**	248
p(r, n) =	0.4211	0.0383	0.0196	**0.0129**	0.0099
pF =	10,537	958	489	**323**	247
$E\gamma$ =	-540.84	-4.99	-0.93	**-0.01**	0.32
$\partial E\gamma/\partial n$ =	548.21	0.50	0.08	**0.02**	0.01
$\partial E\gamma/\partial r$ =	0.5474	0.0498	0.0254	**0.0168**	0.0129
Min F =	$ 23,741	$ 24,895	$ 24,978	**$ 25,025**	$ 25,058

Easy Monitoring: Decreasing Net Gains from Non-Compliance

n =	1	10	**19**	30	40
$E\pi_0$ =	$ 31,212,511	$ 1,032,748	**$ 312,688**	$ 130,294	$ 74,561
$E\pi_1$ =	31,206,265	1,031,612	**312,063**	129,891	74,256
$E\delta$ =	6,246	1,136	**625**	403	305
p(r, n) =	0.3810	0.0721	**0.0398**	0.0257	0.0195
pF =	5,980.95	1,131.53	**624.88**	403.86	305.60
$E\gamma$ =	264.99	4.35	**0.00**	-0.60	-0.62
$\partial E\gamma/\partial n$ =	-274.74	-1.29	**-0.14**	-0.01	0.00
$\partial E\gamma/\partial r$ =	0.4952	0.0937	**0.0517**	0.0334	0.0253
Min F =	$ 16,396	$ 15,760	**$ 15,700**	$ 15,677	$ 15,668

Table II: Across the Board Resource Reductions (0.01)

Industry Structure

Difficult Monitoring		Easy Monitoring	
a =	10,000	a =	10,000
b =	1	b =	0.8
c_0 =	3	c_0 =	6
c_1 =	5	c_1 =	7
α =	**0.92**	α =	**0.44**
r =	**4.99**	r =	**4.99**
F =	25,025	F =	15,700
p(r, n) =	(1-1/r)(1/(n+.9))	p(r, n) =	(1-1/r)(1/(n+1.1))

Difficult Monitoring: Increasing Net Gains from Non-Compliance

n =	1	20	40	**61**	80
$E\pi_0$ =	$ 24,985,002	$ 227,484	$ 59,917	**$ 26,312**	$ 15,474
$E\pi_1$ =	24,975,006	226,531	59,429	**25,989**	15,226
$E\delta$ =	9,996	953	489	**323**	248
p(r, n) =	0.4211	0.0383	0.0196	**0.0129**	0.0099
pF =	10,537	958	489	**323**	247
$E\gamma$ =	-540.84	-4.99	-0.93	**-0.01**	0.32
$\partial E\gamma/\partial n$ =	548.21	0.50	0.08	**0.02**	0.01
$\partial E\gamma/\partial r$ =	0.5474	0.0498	0.0254	**0.0168**	0.0129
Min E =	$ 23,741	$ 24,895	$ 24,978	**$ 25,025**	$ 25,058

Easy Monitoring: Decreasing Net Gains from Non-Compliance

n =	1	10	**19**	30	40
$E\pi_0$ =	$ 31,212,511	$ 1,032,227	**$ 312,373**	$ 130,083	$ 74,399
$E\pi_1$ =	31,206,265	1,031,092	**311,748**	129,680	74,094
$E\delta$ =	6246	1136	**625**	403	305
p(r, n) =	0.3808	0.0720	**0.0398**	0.0257	0.0195
pF =	5,977.96	1,130.96	**624.56**	403.66	305.44
$E\gamma$ =	267.98	4.63	**-0.00**	-0.73	-0.80
$\partial E\gamma/\partial n$ =	-276.34	-1.35	**-0.16**	-0.02	0.00
$\partial E\gamma/\partial r$ =	0.4953	0.0937	**0.0517**	0.0334	0.0253
Min E =	$ 16,404	$ 15,764	**$ 15,700**	$ 15,672	$ 15,659

Table III: Differential Resource Reduction

Industry Structure

Difficult Monitoring		Easy Monitoring	
a =	10,000	a =	10,000
b =	1	b =	0.8
c_0 =	3	c_0 =	6
c_1 =	5	c_1 =	7
α =	**0.83**	α =	**1**
r =	**4.98**	r =	**5**
F =	25,025	F =	15,700
$p(r, n)$ =	(1-1/r)(1/(n+.9))	$p(r, n)$ =	(1-1/r)(1/(n+1.1))

Difficult Monitoring: Increasing Net Gains from Non-Compliance

n =	1	20	40	**61**	80
$E\pi_0$ =	$ 24,985,002	$ 227,337	$ 59,838	**$ 26,259**	$ 15,433
$E\pi_1$ =	24,975,006	226,384	59,350	**25,936**	15,185
$E\delta$ =	9,996	953	488	**323**	247
$p(r, n)$ =	0.4206	0.0382	0.0195	**0.0129**	0.0099
pF =	10,526	957	489	**323**	247
$E\gamma$ =	-530.26	-4.34	-0.76	**-0.01**	0.24
$\partial E\gamma/\partial n$ =	542.47	0.46	0.06	**0.02**	0.01
$\partial E\gamma/\partial r$ =	0.5475	0.0498	0.0254	**0.0168**	0.0129
Min F =	$ 23,764	$ 24,912	$ 24,986	**$ 25,025**	$ 25,049

Easy Monitoring: Decreasing Net Gains from Non-Compliance

n =	1	10	**19**	30	40
$E\pi_0$ =	$ 31,212,511	$ 1,032,748	**$ 312,688**	$ 130,294	$ 74,561
$E\pi_1$ =	31,206,265	1,031,612	**312,063**	129,891	74,256
$E\delta$ =	6,246	1,136	**625**	403	305
$p(r, n)$ =	0.3810	0.0721	**0.0398**	0.0257	0.0195
pF =	5,980.95	1,131.53	**624.88**	403.86	305.60
$E\gamma$ =	264.99	4.35	**-0.00**	-0.60	-0.62
$\partial E\gamma/\partial n$ =	-274.74	-1.29	**-0.14**	-0.01	0.00
$\partial E\gamma/\partial r$ =	0.4952	0.0937	**0.0517**	0.0334	0.0253
Min F =	$ 16,396	$ 15,760	**$ 15,700**	$ 15,677	$ 15,668

Table IV: Restrictions on the Magnitude of the Fine

Difficult Monitoring Industry Structure

a =	10,000
b =	1
c_0 =	3
c_1 =	5
α =	**1**
r =	**4**
F =	25,025
p(r, n) =	(1-1/r)(1/(n+.9))

Difficult Monitoring: Increasing Net Gains from Non-Compliance

n =	1	20	40	**61**	80
$E\pi_0$ =	$ 24,985,002	$ 227,484	$ 59,917	**$ 26,312**	$ 15,474
$E\pi_1$ =	24,975,006	226,531	59,429	**25,989**	15,226
$E\delta$ =	9,996	953	489	**323**	248
p(r, n) =	0.3947	0.0359	0.0183	**0.0121**	0.0093
pF =	9,878	898	459	**303**	232
$E\gamma$ =	117.71	54.88	29.67	**20.21**	15.79
$\partial E\gamma/\partial n$ =	201.60	-2.36	-0.67	**-0.30**	-0.18
$\partial E\gamma/\partial r$ =	0.5592	0.0508	0.0260	**0.0172**	0.0131
Min $\underline{F}$ =	$ 25,323	$ 26,554	$ 26,643	**$ 26,693**	$ 26,728

Table V: The Impact of Entry on the Level of Resources Necessary to Maintain Universal Compliance

Industry Structure

Difficult Monitoring		**Easy Monitoring**	
a =	10,000	a =	10,000
b =	1	b =	0.8
c_0 =	3	c_0 =	6
c_1 =	5	c_1 =	7
α =	1	α =	1
r =	**5.002**	**r =**	**4.996**
F =	25,025	F =	15,700
p(r, n) =	(1-1/r)(1/(n+.9))	p(r, n) =	(1-1/r)(1/(n+1.1))

Difficult Monitoring: Increasing Net Gains from Non-Compliance

n =	1	20	40	**62**	80
$E\pi_0$ =	$ 24,985,002	$ 227,484	$ 59,917	**$ 25,488**	$ 15,474
$E\pi_1$ =	24,975,006	226,531	59,429	**25,170**	15,226
Eδ =	9,996	953	489	**318**	248
p(r, n) =	0.4211	0.0383	0.0196	**0.0127**	0.0099
pF =	10,538	958	490	**318**	247
Eγ =	-541.90	-5.09	-0.97	**-0.01**	0.30
∂Eγ/∂n =	548.76	0.51	0.08	**0.02**	0.01
∂Eγ/∂r =	0.5474	0.0498	0.0254	**0.0165**	0.0129
Min F =	$ 23,738	$ 24,892	$ 24,975	**$ 25,025**	$ 25,055

Easy Monitoring: Decreasing Net Gains from Non-Compliance

n =	1	10	**20**	30	40
$E\pi_0$ =	$ 31,212,511	$ 1,032,748	**$ 283,645**	$ 130,294	$ 74,561
$E\pi_1$ =	31,206,265	1,031,612	**283,050**	129,891	74,256
Eδ =	6,246	1,136	**595**	403	305
p(r, n) =	0.3809	0.0721	**0.0379**	0.0257	0.0195
pF =	5,979.67	1,131.29	**595.13**	403.77	305.53
Eγ =	266.27	4.59	**0.00**	-0.52	-0.55
∂Eγ/∂n =	-275.35	-1.32	**-0.12**	-0.02	0.00
∂Eγ/∂r =	0.4953	0.0937	**0.0493**	0.0334	0.0253
Min F =	$ 16,399	$ 15,764	**$ 15,700**	$ 15,680	$ 15,672