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AN APPLICATION OF A PRINCIPAL-AGENT MODEL WITH MORAL HAZARD

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ABSTRACT

This paper provides a general framework for the design of an efficient government monitoring and enforcement program to reduce the occurrence of random externalities. The role of government monitoring is derived explicitly in a principal-agent model where the government determines the probability of detection and appropriate penalties. The U.S. Coast Guard's oil spill prevention program is analyzed in this manner. It is estimated that the current penalty for spilling oil may be too low for very large spills, and that government expenditures on enforcement could be reduced. Furthermore, the current policy that requires cleanup of all spills may be socially inefficient for small spills.

I. Introduction

The purpose of this paper is to provide a general framework in which to analyze monitoring and enforcement of regulations designed to reduce stochastic externalities. Examples of stochastic pollution include nuclear power plants, oil spills, and hazardous waste dumps. EPA's chemical premanufacturing notification program for toxic substances is another example. In addition, many health and safety issues may be thought of in this manner, such as OSHA's regulation of the workplace and FDA's regulation of prescription drugs and food additives. A final example may be the FTC's auto defect program, which is designed to redress consumers for systematic defects that occur after a manufacturer's warranty period has expired.

The problem of externalities and their theoretical solutions has received considerable attention in the economics literature. We know, for example, that pollution should be controlled so as to equate marginal costs with marginal benefits. Implementing this rather simple rule, however, is not a straightforward exercise. The effectiveness of any regulation will depend on the level of compliance by those firms being regulated. Furthermore, the level of firm compliance will ultimately depend on the effectiveness of the regulatory authority in enforcing its standard.

When pollution is a random occurrence and the regulator does not have full information about its source or size, the enforcement strategy chosen by the regulator is especially important. Regulatory agencies have a host of possible enforcement tools at their disposal, such as direct monitoring, unannounced inspections, _ex post_ fines and penalties, as well as more implicit types of enforcement such as implied threats and harassment. These tools must be evaluated on the basis of both their productivity in achieving the desired results and their cost of implementation.

In the past, much of the economics literature on monitoring and enforcement has focused only on the firm's side of the problem. In the case of pollution, Harford (1978) first investigated the problem of a firm subject to imperfect monitoring. More recently, Beavis and Walker (1983) examined the behavior of stochastically polluting firms subject to random monitoring by the government. Epple and Visscher (1984) developed and estimated such a model of firm behavior in the case of oil transport vessels. They demonstrated that firms in this industry respond to various degrees of government enforcement. However, all of these previous studies have taken as given the choice of enforcement tools used by the regulator. They then examine how an expected profit maximizing firm responds to enforcement. None of these papers have explored the underlying motivation for choosing an enforcement strategy.

This paper is concerned with characterizing the optimal enforcement strategy for a government regulator, taking into account the expected reactions of the regulated firms. Once a regulatory standard has been determined, the problem of the regulator is to design an enforcement scheme that provides incentives for the firm to spend its resources to prevent and control pollution. However, since enforcement is costly, the optimal enforcement mechanism may be one in which *ex post* the regulator does not observe all polluters (and thus some firms may regret their expenditures on pollution), but *ex ante* the firm chooses the action desired by the regulator based on its subjective probability of being detected.

In many ways, this problem can be viewed as a principal-agent model with moral hazard. The principal is assumed to be a government with regulatory authority over firms. The agent is a firm that stochastically pollutes the environment. Moral hazard results from the fact that the firm must take some costly (unobservable) action to reduce the likelihood of pollution. The "contract" is a penalty function that a firm must pay the government if it pollutes. In a manner similar to that in the principal-agent literature, we can examine the conditions under which a simple penalty scheme will produce a first-best solution. When the first-best solution cannot be achieved, we can determine when monitoring may improve on the nature of the solution. In this manner, the need for various types of monitoring activities as enforcement tools can be endogenously derived.

Section 2 describes how the optimal enforcement strategy can be derived from well-known results in the principal-agent literature. Section 3 briefly examines various assumptions about the prevention technology, information structure and preferences that alter the basic results shown in section 2. Section 4 focuses on one example of a government-pollution problem, the U.S. Coast Guard's oil spill prevention program. It is shown how the earlier theoretical analysis can be applied to a real-world problem. Some policy implications of this analysis are contained in section 5. Several concluding remarks are reserved for section 6.

II. Regulatory Compliance and Moral Hazard

The principal-agent problem has been used to model many economic relationships involving risk-sharing and incentives. Three often cited examples are sharecropping, the employee-employer relationship, and insurance.[1] The common thread running through these problems is the existence of an agent who takes some action that affects the probability distribution of a random occurrence. This random occurrence affects the utility of both the agent and a principal. Since it is the agent's action that affects the utility of the principal, the interesting economic question is to characterize a contract between the two parties that will provide the agent with incentives to choose the optimal level of effort.

If the principal cannot observe the action taken by the agent, the problem of moral hazard arises. The principal is unable to enforce the optimal contract, because *ex post* he or she has no way to verify that the agreed upon action was taken.

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[1] For example, see Spence and Zeckhauser (1974), and Stiglitz (1974).

Thus, the problem becomes one of finding a second-best optimum. It has been shown that when the level of effort is observable, or when the agent is risk neutral, a first-best solution can be achieved.[2]

These simple theoretical results have important empirical content. For normative analysis, one can answer the question of how a contract should be designed in order to induce the appropriate action by the agent. For positive economic analysis, these results can often be used to explain such contractual arrangements.

The principal-agent literature provides a convenient framework in which to analyze the problem of a government regulator who must decide how to enforce its regulations. Shavell (1979) suggested that the problem of regulating a firm that causes random accidents (e.g., environmental damage) may be viewed in this manner. His casual and yet insightful observation was that a strict liability standard (where the firm is liable for damages regardless of the cause of the accident) can be viewed as a principal-agent contract that depends only on the outcome. On the other hand, a negligence standard can be regarded as a contract that depends on information about the agent's level of effort.

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[2] See, for example, Harris & Raviv (1978, 1979), Shavell (1979) and Holmstrom (1979).

Using the results of his paper, Shavell asserts that if the firm is risk neutral, a strict liability approach would be adequate. However, if the firm is risk averse, a negligence standard may be needed to keep the firm from leaving the industry or over investing in preventive care. He concludes this discusion by cautioning that the choice between strict liability and negligence standards also depends on other factors, such as the quality and cost of information.

If Shavell's analogy is taken literally, there is no reason for the government to monitor the actions of a risk neutral firm.[3] As long as there is a positive probability of being detected, the government should be able to induce optimal behavior (e.g., compliance) with an ex post penalty equal to the social damages of pollution (adjusted upward to account for the probability of detection).[4] Yet, in practice, the government devotes considerable resources to monitoring the level of compliance with its regulations. In this section, we will ignore the question of why the government monitors potential polluters.

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[3] Throughout this paper, a distinction is made between enforcement resources designed to detect the source of an externality and those spent on monitoring the level of care taken by a regulated firm to prevent an externality from occurring.

[4] The economics of crime literature has addressed some of these issues. For example, see Becker (1968). However, the issue of whether or not monitoring is needed has not generally been addressed in this context, since it is assumed that crime is not stochastic, but clearly "caused" by the criminal.

Instead, we will focus on characterizing the conditions under which no monitoring is required.

Consider a firm that randomly causes an externality (x) as a byproduct of its production process.[5] Although the firm is unable to directly control the externality, it can alter the underlying probability distribution. In particular, the firm can take some level of effort "e" to shift the distribution, F(x,e), and reduce the expected size of the externality.[6]

The government may require that a certain level of effort be expended by firms. If so, the firm may be inspected for compliance. With probability $P_I(m_1)$, the firm will be inspected, where m_1 is the level of government resources devoted to <u>ex ante</u> monitoring. If inspected, the firm must pay a fine $T_1(e)$, which decreases with the observed level of effort. Presumably, this penalty is zero if the firm is found to be in compliance with the regulations specifying the expected level of effort.

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[5] The following specification of the firm's problem is adapted from the model of the firm in Epple and Visscher (1984).

[6] There are two types of action the firm can take. First, it may take preventive measures, such as increasing R&D efforts before introducing a new chemical, or installing backup equipment to prevent leakage of untreated wastes. The second type of action a firm may take is designed to reduce the damage caused by an event. This may be thought of either as an action taken subsequent to an event's occurrence, or as an action taken prior to a polluting event whose sole purpose is to reduce the size of pollution <u>if</u> it occurs. An example of the former would be employing an emergency crew to contain the amount of pollution emitted once an accident happens, while an example of the latter would be the installation of backup containment equipment.

If an externality is generated, the probability that the firm will be detected by the government is $P_D(x,m_2)$, where m_2 is the amount of government resources devoted to detection. If the firm is detected, the government will impose a penalty $T_D[x,e(m_3)]$, where m_3 is <u>ex post</u> monitoring of the firm's level of effort.[7] In addition, the firm may incur some private loss $v(x)$, such as the value of lost resources.[8] With the above notation, and an assumption of risk neutrality on the part of the firm, the firm's expected profit can be written as:[9]

$$EU(e) = - P_I T_I(e) - \int_x [v(x) - P_D(x) T_D(x,e)]\, f(x,e)dx - e \quad (1)$$

The government (principal) is assumed to be a social welfare maximizer. Thus, it wants to minimize the sum of environmental damages $D[(1-r)x]$, cleanup or recovery costs $C(rx)$, private loss $v(x)$, preventive expenditures e, and monitoring expenses m_1 and

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[7] The monitor m_3 may not perfectly reveal the level of effort. See Harris and Raviv (1979).

[8] Examples of these costs include the value of oil lost in an oil spill, the replacement cost of equipment lost in an explosion, and the inventory of a chemical or drug taken off the market.

[9] Throughout this paper, the main economic activity of the firm is ignored. Assuming the firm operates in a competitive industry, any increased cost of prevention will be fully passed through in the price of the product. Of course, that does not mean that the firm can simply take an infinite amount of preventive measures. In fact, since the firm is competitive, it is forced by the market to take the same preventive measures as all other firms.

m_3, and detection expenses m_2. r is the fraction of any pollution that is recovered or cleaned up. It is chosen by the government so that given pollution of size x, $D[(1-r)x] + C(rx)$ is minimized. In other words, the government announces that for pollution of size x, $(1-r)x$ may remain in the environment and rx must be cleaned up. The government's choice of r will depend on the cleanup technology and damage function. Of course, for some types of pollution, cleanup is impossible, and all of the penalty consists of "damage" costs. Thus, the principal's expected utility (social welfare) may be written as:

$$EW(e,m_1,m_2,m_3) = \int_x [D((1-r)x)+C(rx)+v(x)]f(x,e)dx-e-m_1-m_2-m_3 \quad (2)$$

Implicit in the above specification is the fact that the principal is indifferent to the level of the fine paid by the firm, $W'(T) = 0$. The fine is only a transfer of wealth and does not directly represent any real resource cost. By excluding the penalty from the principal's utility function, we are adhering to an assumption used implicitly in many models of the principal-agent problem. Specifically, it is often assumed that the principal's utility is separable in x and T. In other words, the marginal rate of substitution between x and T is independent of T. In terms of this model, that assumption is equivalent to saying that society's marginal evaluation of pollution is independent of the level of the penalty imposed. Obviously, since the government is assumed to be indifferent to the level of the penalty, this assumption holds. In section 3(c), we will examine the implications of relaxing this assumption.

A social welfare maximizing regulator will choose a desired level of (firm) effort, (government) monitoring and detection expenses, and recovery rate to maximize (2). This can be done by setting $m_1 = m_2 = 0$, and setting e such that $-\int_x [D((1-r)x) + C(rx) + v(x)]f_e(x,e)\,dx = 1$. That is, the marginal social benefit of an increased level of effort is equated to its marginal cost (assumed here to be unity).

However, since the regulator cannot directly control the firm's level of effort, it must devise a penalty (contract) whereby the firm finds it in its own interest to choose the socially optimal level of effort.

With the above specification, it is easy to specify a penalty that will maximize social welfare. In particular, consider the following penalty function:

$$T_D(x) = \frac{D[(1-r)x] + C(rx)}{P_D(x)} \tag{3}$$

Substituting (3) into (1) yields (2), the social welfare function with zero monitoring and detection expenses. Thus, the firm is induced to choose the level of effort e that maximizes social welfare, without devoting government resources to monitoring.

In addition to specifying this penalty function, the government must also choose the recovery rate (r). This is chosen so that $D'(r) = C'(r)$, equating the marginal cleanup costs to marginal damages. Notice that as long as r is chosen optimally, it will not affect the firm's choice of e. Thus, the decision process for choosing a penalty and recovery rate are independent of each other.

This optimal penalty function has a rather intuitive interpretation. If all pollution was detected ($P_D(x)=1$), (3) would equate the expected penalty to the expected environmental damage plus cleanup cost. In this way, the penalty would make the firm take into account the social costs of its actions in addition to the private costs already accounted for by its maximization problem. However, the probability of detection is also taken into account when determining the penalty function.[10] For example, if $P_D(x)=1/2$, then the portion of the penalty that is based on environmental damage and cleanup cost is doubled. Even though the firm who is detected pays more than the social cost of pollution and the undetected polluter pays nothing, the threat of paying this high penalty provides the proper incentive for both firms to take the optimal level of care.[11]

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[10] The issue of adjusting a penalty to account for the probability of detection has been studied extensively in the economics of crime literature. For example, see Polinsky and Shavell (1979).

[11] This discussion suggests a potential problem for the government. If the firm is able to affect the probability of detection, even at some cost, it may be profitable to do so. The natural response of the government in this model is to increase the size of the penalty to compensate for this lower detection rate. But this system creates an enormous incentive for all firms to avoid detection. If this happens, the government may have to counter with its own effort to increase the probability of detection. This problem is discussed further in section 3(B).

Obviously, equation (3) does not hold if $P_D(x) = 0$. That is, if there is no chance of being detected, there is no penalty function that will induce the firm to take the optimal level of effort. In such a case, some minimal level of detection-related expenditures m_2 would be needed to achieve a positive detection probability.

Note that there is never a need for monitoring (m_1 and m_3) in this simple model. This follows immediately from the fact that some minimal level of m_2 (detection) will permit the use of the penalty function (3).

Although (3) is an optimal penalty function, this does <u>not</u> rule out the possibility that a penalty function depending on the level of effort can achieve the same level of effort as the optimal penalty function (3). If information about the level of effort was somehow available at no cost to the government, then another penalty function (contract) could be constructed that would also yield the first-best solution. In particular, the following "forcing" contract[12] <u>will</u> yield the same level of effort by the firm:

$$T_D(x,e) = \begin{cases} \dfrac{D[(1-r)x] + C(rx)}{P_D(x)} & \text{if } e < e^* \\ 0 & \text{if } e > e^* \end{cases} \qquad (4)$$

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[12] See Harris and Raviv (1979) for a discussion of forcing contracts.

where e* solves equation (2). This penalty is based on a negligence standard. The firm is penalized only if the pollution was "caused" by the firm's lack of preventive care. The penalty shown in (3) is a strict liability standard, since the firm that pollutes is penalized irrespective of its level of effort.

Although the strict liability and negligence standards both induce the socially optimal level of care, the latter requires more information on the part of the principal. Specifically, the government must monitor the level of effort. Since monitoring is costly, the strict liability standard provides a higher level of net social welfare. Thus, a negligence standard should not be used by a social welfare maximizing principal when monitoring is costly.[13]

If we deviate slightly from the static nature of this model and consider a somewhat dynamic setting, there may be another important reason to prefer a strict liability rule. Suppose the government believes there is room for technological improvements that would reduce the probability and/or size of pollution for a

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[13] This result holds as long as there is some positive probability of detecting the agent at no cost to the principal. In the standard principal-agent model, this "detection" problem never arises, since the principal is assumed not to have any problem identifying his or her agent. In many problems of government regulation, some detection is also automatic. For example, the Coast Guard will detect some oil spills while carrying out its other duties. In other cases, members of the public who are affected by externalities are likely to bring them to the attention of the regulatory authorities. Even if there is no automatic detection, there is likely to be some very minimal amount of expenditure that will yield a positive detection rate.

given level of effort. Then the strict liability standard provides the firm with an incentive to invest in R&D to find a better technology,[14] since the firm must pay for all damages. On the other hand, if the negligence standard is used, there is no incentive to invest in R&D, since the prespecified "optimal" level of effort depends only on current technology.

Not only does information about the firm's action have no value, but any ex post information other than the actual spill size is irrelevant. Specifically, note that the optimal penalty does not depend on the technololgy. For example, consider an oil transportation firm. If the size of an oil spill depends on vessel size, $x(e,s)$, the ex post penalty would remain unchanged even though the ex ante expected penalty will depend on s.

The following example will help illustrate this point:

Let: $E(x) = 1 - (b-s)^{1/2}$, where $E(x)$ is the expected value of x.

$D(x) = 2x$

In this simplified example, it is assumed that all spills are detected and none are cleaned up. Furthermore, the value to the firm of any spilled oil is simply $v(x) = px$, the price of oil. Therefore, the government's problem is to:

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[14] This is essentially the argument used by Posner (1972) in his discussion of negligence versus strict liability laws.

$$\underset{\{e\}}{\text{Maximize}} \quad -(2 + p)\ [\ 1 - (e-s)^{1/2}\ ] - e$$

The firm's problem is:

$$\underset{\{e\}}{\text{Maximize}} \quad -\ p\ [\ 1 - (e-s)^{1/2}\ ] - T - e$$

Thus, the <u>expected</u> penalty is:

$$E(T) = 2\ [\ 1 - (e-s)^{1/2}\ ]$$

The first order condition for a maximum yields the following:

$$.5\ (2 + p)\ (e - s)^{1/2} = 1$$

$$e* = .25\ (2 + p)^2 + s$$

Since the price of preventive effort e has been assumed to be unity, this condition just equates the expected marginal social cost with the expected marginal social benefit of preventing a spill. Clearly, the optimal e* will depend on the vessel size. In this example, since a larger vessel means a larger expected spill volume, $\partial e^*/ \partial s > 0$, so that larger vessels spend more on prevention. However, the <u>ex post</u> penalty is just $T_D = 2x$. It is the fact that larger vessels have higher <u>expected</u> penalties that induces the firm to choose the optimal e*(s); the <u>ex post</u> fine is not relevant to that decision.

To summarize the main result of this section, the optimal penalty for a risk neutral profit maximizing firm is an <u>increasing</u> function of the social damages caused by the externality that actually occurs and any cost associated with its cleanup or recovery. It is a <u>decreasing</u> function of the probability of being detected. Finally, it is <u>not</u> a function of the level of effort of the firm, any firm-specific technology, or the value of any lost private resources.

The search for an optimal enforcement strategy to control random externalities is similar in many respects to the analysis of optimal law enforcement in Becker (1968), and the penalty function shown in this section is identical to Becker's. However, Becker's approach to law enforcement is a special case of a principal-agent model, one in which social harm occurs if and only if the agent (criminal) takes some action (violates the law). In the case of stochastic externalities, social harm may sometimes occur even if the agent did not take any socially harmful action. For example, an oil spill may be caused by an unforeseen weather-related event, not any negligent action on the part of the oil vessel operator. Thus, in Becker's problem, the principal (government) knows that a criminal act has occurred and the question becomes one of detecting the violator. In this paper (and more generally), even if the source of the socially harmful event is detected, there may be a need to monitor the actions of the agent who "caused" the event, to determine if a law violation actually occurred.[15]

This result will not be surprising to those familiar with the principal-agent literature. It is well known that if the agent is risk-neutral, the first-best solution can be achieved

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[15] Circumstances in which monitoring may be desirable are discussed in the next section.

without monitoring the level of effort. Instead, this result has important policy implications not often addressed in the literature on regulation. In particular, since government regulators often devote considerable resources to monitor firm compliance, one may ask if this is a good use of government resources. Of course, the model presented here is very simplistic, and there may be reasons outside this model that one should monitor either (both) the level of compliance or (and) the source of the externality. The next section will examine conditions under which some monitoring may be desirable.[16]

III. Alternative Assumptions and the Role of Monitoring

From the previous section, it would appear that if the agent is risk neutral, there is no need for the principal to monitor the agent's level of effort. For a government regulator, this would imply that the government could merely set a penalty function based on any *ex post* pollution. There is no need to monitor the level of effort of the firm. However, this result is based on specific assumptions about preferences and technology that may not hold in many real life applications. This section

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[16] Although this paper focuses on the normative aspects of monitoring, there are interesting positive issues that can also be addressed in this context. In particular, if monitoring is not efficient, one may ask why it is often used by government regulators. The answer to this question may be found in the incentives facing government regulators and politicians. For example, Lee (1983), (1984), considers the incentives of budget maximizing bureaucrats to monitor compliance with pollution control regulations.

examines alternative assumptions to the basic model presented in Section 2. It will be shown that (unlike in the basic model) under various conditions, there is a role for monitoring in a government regulator problem.

A. Risk Averse Agent

It is well known that risk aversion on the part of the agent is sufficient to introduce potential gains to monitoring the agent's action.[17] If a firm is risk averse, it prefers a certain penalty to its expected value. One way for the risk averse firm to obtain a higher expected utility is to overinvest in preventive measures. Thus, the firm will pass on a risk premium to its customers. Not only is the higher level of prevention a waste of resources, but the risk premium reduces consumer surplus by the value of decreased purchases due to the higher product price.

Thus, the potential benefits from monitoring arise from gains to trade. Essentially, the firm can "trade" its action for the risky return. By monitoring the agent's action, and not penalizing the firm for "bad draws" of nature, the government bears the risk, presumably through a lump sum tax that does not distort resource allocation.

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[17] For formal proofs of this result, see Shavell (1979), Harris and Raviv (1979), and Holmstrom (1979).

To illustrate this result, consider the example shown in Section 2. Let $u(.)=y^{1/2}$, where y is the sum of pollution-related costs. Suppose a spill occurs with probability .5, and that given a spill, $E(x)=1-e^{1/2}$. Also, let the price of oil equal one. Then, expected utility for the firm is:

$$E(U) = -.5\{[x + T(x) + e]^{1/2}\} - .5e^{1/2}.$$

The government can induce socially optimal behavior by setting the penalty such that:

$$E\{[x + T(x) + e]^{1/2}\} = -e^{1/2} + 2e + 6E\{x\}$$

The solution to this problem depends on e. Unlike the risk neutral case, the penalty cannot be expressed solely in terms of the <u>ex post</u> spill size. Thus, in order to obtain the first-best solution, the principal would have to observe the level of effort of the agent.

Of course, if monitoring is costly, then any potential gains from monitoring must be weighed against those costs. This may affect the actual level of e* and the penalty size, but the qualitative aspects of the solution are unaffected.

If the agent is risk averse, we would expect the penalty to depend not only on the <u>monitor</u> of the firm's action, but also on any firm-specific variables that affect the technology of pollution prevention. For example, if larger oil transport vessels require a higher level of effort, the optimal penalty will depend on vessel size as well as on the monitor itself. In this case, holding the observed monitor constant, a larger vessel size will mean a larger penalty.

B. The Detection Problem

Instead of depending only on the size of x, the probability of detection may depend on firm-specific characteristics. For example, suppose the probability of detecting an oil spill depends on vessel size. That is, $P_D = P_D(x,s)$. Presumably, smaller vessels have a better chance of evading detection, so that $P_D'(s) > 0$. Since the optimal penalty is decreasing in P_D, this would suggest the penalty is decreasing in vessel size.

The detection problem mentioned earlier (in footnote 11) may also lead to slightly different results. It may be possible for firms to devote resources to evade government authorities and lower the probability that they will be detected. At first, it would seem that our model can easily handle this possibility by automatically increasing the penalty to account for the new detection rate. However, the fact that P_D now differs across firms with the same basic detection technology provides an incentive for all firms to avoid detection.

One obvious response to this problem is to require full disclosure by any firm that has polluted, and severely penalize any firm caught polluting but not reporting it to the government. Implementing this type of penalty is relatively straightforward as long as there is some positive probability of being independently detected by the government.[18]

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[18] In fact, many regulatory enforcement programs are set up in this fashion. For example, the Coast Guard can impose criminal sanctions for failure to notify it when oil is spilled in U.S. waters.

C. Principal's Utility Depending on Size of Penalty

Some of the standard results of the principal-agent literature do not hold if the principal's utility is nonseparable in the outcome and fee structure. For example, if the government's valuation of pollution depends on the wealth of the firm (which depends on the magnitude of the fine imposed), there may be gains to monitoring.[19] That is, the government now has a stake in the welfare of the polluting firm and prefers prevention to punishment.

D. Uncertain Prevention Technology

One possible reason for monitoring the agent's action is that the government may want to learn more about the distribution F(x,e). That is, the government may not be certain about what causes the stochastic polluting event. Further, they may not be certain about the extent to which preventive measures can reduce the probability or size of these events. However, even if the government wished to learn more about the abatement technology, there is no need to base the penalty on the monitored level of effort.

This is not the same problem cited earlier about technological advances. If the government is interested in inducing R&D to find more productive preventive measures, then a strict liability standard is appropriate. Otherwise, the firm has no incentive to look for technological improvements.

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[19] See Banker and Maindiratta (1983).

E. Choosing the Level of Effort After Observing the State of Nature

In some cases, the firm is able to observe the state of nature prior to choosing its level of effort. For example, in the case of oil transport vessels, the weather may be thought of as a state of nature. After observing the state of the weather, a vessel operator may decide to postpone a shipment, or take some precautionary measures to reduce the probability of an accident. Of course, there are likely to be other preventive measures of a more long term nature (such as the purchase of better navigation equipment) that are not likely to be affected by the weather.

This case has been studied extensively in the literature.[20] As long as the principal's utility is separable in the outcome and the penalty, there is no need for monitoring. As discussed earlier, it is reasonable in most of these models to assume separability. In fact, we have assumed throughout the $U'(T)=0$.

F. Bankruptcy or Limited Liability

Until now, it has been assumed that a firm who is penalized by the government will actually pay whatever penalty is asessed. However, if the firm's liability for damages is limited, or if it

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[20] For example, this is precisely Model 2 in Harris and Raviv (1978), (1979).

may opt to declare bankruptcy, the problem changes considerably.[21]

One would expect that since the firm is able to declare bankruptcy in some of the "worst" states of nature, it has an incentive to take "too much" risk. Intuitively, bankruptcy ought to make a risk neutral agent risk loving. The agent is now willing to take less care and reduce the certain costs of prevention in exchange for the risk of a bad state of nature, since this bad state of nature is not as costly to the agent with the bankruptcy provision.

Although a higher penalty will induce firms to take more care, it also has the effect of increasing the probability of a bankruptcy, which decreases the level of care. It is therefore in the interest of the principal to set a penalty function that has a lower expected cost to the agent (thus reducing the probability of a bankruptcy), without creating an offsetting incentive for the agent to reduce its level of care. One such penalty scheme is a negligence standard, where the principal monitors the effort level of an agent <u>after</u> the realization of x, and penalizes the agent only if the agent's effort is deemed to have

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[21] The issue of bankruptcy has received some attention in the literature. In the context of a sharecropper, Braverman and Stiglitz (1982) found that bankruptcy decreased the agent's aversion to risk. Sappington (1983) examined a general principal-agent model in which the agent observes the state of nature prior to taking any action. He showed that the nature of the contract changed considerably when the agent was allowed to renege on the contract after observing the state of nature.

been unacceptable. In this way, firms are not penalized for polluting events that were not "caused" by their lack of care. This reduces the expected penalty size, which also lowers the probability of a bankruptcy. By lowering the bankruptcy probability, the negligence standard can induce a higher level of care than the strict liability standard.

The following numerical example illustrates how a penalty depending on the level of care may be able to yield the first-best solution when a penalty depending only on the outcome (spill size) may not. For simplicity, assume the probability of being detected is P_D=.3, and that no spills are cleaned up. Environmental damages are $2x^2$, and the price of oil is unity. The technology is such that the firm has two choices: it can take no care (e=0), or it can spend one unit on care (e=1). The spill size distribution is given by:

If e = 0, x = 1 with probability .4
2 with probability .6
If e = 1, x = 1 with probability .6
2 with probability .4

Without any government intervention, the firm will choose e such that its expected profit is maximized, where:

EU(e=0) = -.4(1) - .6(2) = -1.6

EU(e=1) = -.6(1) - .3(2) - 1 = -2.4

Thus, the firm will choose to take no care (e=0). However, expected social welfare is maximized as follows:

$$EW(e=0) = -.4(1) - .6(2) - .4(2) - .6(8) = -7.2$$

$$EW(e=1) = -.6(1) - .4(2) - .6(2) - .4(8) - 1 = -6.8$$

Thus, the socially optimal level of prevention is e=1. The firm's expected profit when facing a penalty T(x) becomes:

$$EU(e=0) = -1.6 - .4(3)T(1) - .6(.3)T(2)$$

$$EU(e=1) = -2.4 - .6(.3)T(1) - .4(.3)T(2)$$

A first-best penalty function that induces social welfare maximization is simply $T(x) = 2x^2/P_D$, the <u>ex post</u> environmental damage divided by the probability of detection. Thus, a firm that spills one gallon and is detected would be fined 6 2/3, and a firm that is caught spilling 2 gallons would be fined 26 2/3. Furthermore, there is no need to monitor the level of care. Now, suppose there is an exogenously imposed liability limit, K = 10. Any first-best penalty depending only on x must solve:

$$-1.6 - .4(.3)T(1) - .6(.3)T(2) < -2.4 - .6T(1) - .4T(2) \quad (4)$$

$$0 < T(1) < 10 \quad (5)$$

$$0 < T(2) < 10 \quad (6)$$

But (4) can be rewritten $T(2) - T(1) > 13\ 1/3$. This violates (5) and (6). Thus, there is <u>no</u> first-best penalty depending only on x.[22]

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[22] Note, equations (5) and (6) rule out governmental subsidies in the place of penalties. If the government is willing to subsidize firms that only spill one gallon of oil, a first-best can be achieved.

Instead, consider a penalty that also depends on e. For simplicity, consider only penalties of the form T(x) + S(e). Then, a first-best penalty of the form T(x) + S(e) must solve:

$$1.6 + .12T(1) + .18T(2) + .3S(0) < 2.4 + .18T(1) + .12T(2)$$

$$+.3S(1) = 6.8$$

$$0 < T(i) + S(j) < 10 \quad \text{for } i=1,2; \quad j=0,1.$$

One solution to this problem is T(1) = 6, T(2) = 7, S(0) = 3, S(1) = 0. Thus, this example has shown how (in the presence of limited liability), a penalty depending only on the *ex post* spill size may not achieve the first-best, whereas a penalty depending on the firm's level of effort may do so. In this example, the optimal level of care can only be achieved if the firm's actions are monitored.

IV. Example of Stochastic Pollution: Coast Guard's Oil Spill Prevention Program

A. Background

The purpose of this section is to demonstrate the applicability of the theoretical framework set forth in the previous two sections. In particular, we will consider the U.S. Coast Guard's enforcement of oil spill prevention and cleanup regulations for oil carrying tankers and barges. Unfortunately, data limitations preclude the estimation of the optimal penalty function and monitoring level.[23] Nevertheless, there is much to be learned from the data that is available.

Oil spills are an ideal candidate for a study of this nature, since their occurrence is random. Both the probability of a spill and the size of a spill that has occurred depend on the level of care taken by the ship's owner and crew. Examples of such preventive measures are navigational equipment, proper maintenance and properly trained personnel.

The Water Quality Improvement Act of 1970 prohibits the discharge of oil into U.S. inland or coastal waters. The Act required that all spills be reported to the U.S. Coast Guard and be cleaned up by the discharger. If the polluter does not clean up the oil spill, the Coast Guard is authorized to undertake cleanup and charge the polluter for the costs incurred. The Coast Guard was also given the authority to fine polluting firms $5,000 for each pollution incident.

In this paper, we only consider oil spills caused by oil transportation vessels such as tankers and barges. Although tankers and barges account for about 15 percent of all oil spills, their spilled oil amounts to about one-third of all oil

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[23] One of the key missing data is the distribution of vessel sizes and transfers by location. Without such data, it is not possible to estimate the probability of spilling oil. See Epple and Visscher (1984) for a thorough discussion of this problem and an attempt to circumvent this data limitation.

spilled annually.[24] Furthermore, there is a vast amount of data available about ships that have spilled oil through the Coast Guard's Pollution Incident Reporting System (PIRS) and Quarterly Reports (QAR). Among the variables available from PIRS are the date, location, type of vessel, size and nature of the spill, amount of oil recovered, cause of the spill and any penalty assessed. Other potentially useful data include wind and water speed, affected environmental resources and the cost of cleanup. Unfortunately, many of these other variables are only sporadically reported from the field. The QAR data base includes such variables as the number of oil transfers and the number of hours devoted by the Coast Guard to monitor oil transport vessels.

Due to the mobile nature of oil transport vessels, the Coast Guard cannot detect all spills. The Coast Guard's enforcement policy consists of a combination of detection,monitoring and penalties. Failure to report a discharge of oil to the Coast Guard is a criminal offense, with a maximum penalty of $10,000 and/or one year in jail. Finally, as mentioned above, the polluter is responsible for removal costs plus a penalty of $5,000. Although the law states that a penalty of $5,000 is to be assessed per polluting incident, the actual fines imposed by the Coast Guard have generally been much less.

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[24] See Epple and Visscher (1984), p. 2. Other sources of oil spills include oil storage and transfer facilities and offshore wells.

Although all corporations have limited liability, the maritime industry has a unique limited liability protection under U.S. law. Prior to 1970, a vessel owner was only liable for an amount equal to the remaining interest in the vessel. In an extreme, yet factual example, a U.S. court found that the owners of the supertanker Torrey Canyon were <u>not</u> liable for any damages in excess of $50.00, the value of its only salvaged property, a lifeboat. Yet, the Torrey Canyon caused over $16 million in quantifiable damages off the coasts of Britain and France.[25]

Partly as a result of the Torrey Canyon incident, Congress (in 1970) changed the limit to owner's liability in the case of oil spill cleanup costs. The legal limit to liability was set at $100 per gross ton of the vessel, up to a maximum of $14 million. Thus, a 300 ton ship had a limit of $30,000 in cleanup cost liability. However, this limit apparently proved to be inadequate.[26] Amendments to the Federal Water Pollution Control Act in 1977 (effective beginning in 1978) increased the liability to

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[25] See Burrows, (1974). The owners eventually paid about $3 million in damages to the affected parties, as the spill did not occur in the U.S., and was subject to an International Agreement on liability.

[26] For example, Spitzer (1980), pp. 51-2, cites the case of the tank barge "Dixie Buccaneer" which discharged 1,265,00 gallons of oil into the Mississippi River in 1974. The owner stopped his cleanup activity when the costs reached the liability limit. The Coast Guard was forced to take over the cleanup effort, at a cost of about $1 million.

$150 per ton with a minimum liability of $250,000 for tankers. Inland barges are liable for up to $150 per ton with a minimum liability of $125,000.[27]

B. The Effectiveness of Coast Guard Enforcement

Epple and Visscher (1984) estimated a model in which oil transport firms respond to the level of Coast Guard enforcement by changing their level of preventive efforts. In the notation of the present paper, they would have the firm choose the level of effort "e" to maximize expected profit (1). By substituting the Coast Guard's enforcement level into the penalty functions and probability of detection, one can solve for an equilibrium level of effort, $e^* = g(V, m_1, m_2, m_3)$. Epple and Visscher specify the distribution of oil spills to be log-normal, and thus estimate the mean spill size to be a function of the value of oil, level of Coast Guard enforcement, and spill size variance.[28]

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[27] For an interesting discussion of the legislative history for the liability limits, as well as the political and institutional reasons for maintaining a limited liability, see Spitzer (1980).

[28] Epple and Visscher found that the lognormal distribution fit the data quite well. Note that if Ln x is normally distributed, its mean is $\exp(\mu + \sigma^2/2)$, so that any estimate of Ln x should depend on the variance of the spill size distribution. Epple and Visscher thus estimated spill size using a two step procedure. First, they estimated mean spill size separately in each district as a function of price of oil, vessel size and enforcement. The resultant estimated variances for each district were then used as explanatory variables in the second step.

In addition, vessel size was expected to be an important determinate of spill size, as larger vessels, ceteris paribus, should have larger spills. They found that increased enforcement did lead to lower observed spill volumes.

Table 1 reproduces the estimated oil spill size parameters reported in Table 5 of Epple-Visscher. The only difference between the two estimaes is that here we separate out the type of Coast Guard enforcement. The Coast Guard uses three different monitoring and detection techniques. First, they randomly inspect vessels to check for compliance with oil spill prevention regulations. Second, they selectively observe oil transfer operations while vessels are docked at ports. Third, Coast Guard personnel randomly patrol port areas to look for unreported oil spills.[29]

The estimates shown in Table 1 are generally consistent with those reported by Epple and Visscher. Oil spill size increases with vessel size and decreases with the price of oil. It also decreases with the amount of Coast Guard resources devoted to observing transfer operations and patrolling ports. However, inspections designed to determine if vessels are in compliance

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[29] Vessel inspections correspond to monitoring (m_1) in our model. Random port patrols correspond to detection expenditures, m_2. Observing oil transfer operations probably corresponds to all three types of enforcement, ex ante monitoring (m_1), detection (m_2), and ex post monitoring (m_3).

TABLE 1

Estimated Oil Spill Size Parameters

Variables	Tankers and Barges Combined	Tankers Only	Barges Only
Constant	1.49 (3.97)	1.04 (1.90)	1.94 (2.68)
Price	-0.47 (3.26)	-0.83 (4.09)	-0.17 (0.84)
Vessel Size	0.15 (7.27)	0.12 (3.55)	0.18 (6.00)
Variance	-0.14 (4.87)	-0.17 (4.64)	-0.13 (1.63)
Compliance Inspections	0.03 (0.88)	0.02 (0.29)	0.12 (1.72)
Observe Oil Transfers	-0.17 (3.91)	-0.18 (2.86)	-0.14 (2.05)
Patrol Ports	-0.20 (4.33)	-0.21 (2.74)	-0.18 (3.00)
Observations	6642	2905	3737

Notes: t-statistics reported in parentheses. Data covers all spills reported from 1973-1977. The dependent variable is Ln (Spill Size). Following Epple-Visscher, the price, vessel size and enforcement variables are all expressed as natural logarithms. Inspections and oil transfer observations are measured as the total number of hours per transfer in a given district for each vessel type. Patrols are measured as the total number of hours per transfer in a district (not distinguishable by vessel type).

with oil spill prevention regulations have had no significant effect on spill size.[30]

C. Estimation of Coast Guard Penalty Function

Since firms are required to clean up spills themselves (or they are billed for costs incurred by the government), the observed <u>monetary penalty</u> is:

$$t(x,e) = T(x,e) - C(rx)$$

From equations (3) and (4), we know that this penalty ought to depend on damages, costs, and the probability of detection. It may also depend on the firm's level of effort. Although we do not know the actual environmental damage, cost of cleaning up each spill, or the probabilities of detection, we can specify some of the relevant determinates of these functions. Damages and costs depend on the size of the spill; the fraction remaining in the water; weather related variables such as wind and water speed, time of day, and the seasons; the location of the spill, which determines what resources are affected (such as recreational beaches, fish, etc.); and the type of oil.

The spill size at which bankruptcy occurs (and hence the probability of bankruptcy), depends on the liability limit, which depends on the vessel size as well as the penalty and level of effort.

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[30] It is possible that compliance inspections reduce the <u>probability</u> of a spill occurring, which is not estimated here.

The probability of detection depends on the spill size, vessel size, level of enforcement, and on monitoring technology. It also depends on the detection technology. For example, suppose detection and penalty size are inversely related. Then, to the extent that the detection technology improved over time for a fixed level of monitoring resources, the penalty should decrease over time. In the case of the Coast Guard oil spill detection program, there was a considerable improvement in the detection technology between 1973 and 1977 (the dates included in the empirical analysis described below).[31] To the extent the Coast Guard can more efficiently detect oil spills (and the source of spills), there is less of a need for Coast Guard monitoring of the firm's level of effort. They could maintain the same penalty level and detection rate while decreasing monitoring expenses.

The vessel size variable affects two determinates of the penalty function. Presumably, larger vessels are easier to detect. It is also likely that vessel size affects the probability of bankruptcy. Although it is not clear in which

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[31] During that time, the Coast Guard developed and implemented an airborne surveillance system designed to detect oil spills at night or under adverse weather conditions. They also developed a test to identify the exact composition of any oil sample in order to identify the source of unreported spills. Special laboratories were established in the field so that the local Coast Guard office could use this identification technique when required. For a discussion of these developments, see U.S. Department of Transportation (1978), and Bragaw (1980), pp. 199-200.

direction this dependency should go, it is likely that a larger vessel size will induce a larger penalty if a negligence standard is used. Since a larger vessel has a large potential spill volume, controlling for the "cause" of a spill may not fully account for variations in the penalty size. Instead, the penalty may have to reflect the potential spill volume due to an inadequate level of effort.

Data are available on over 5,000 spills that occurred from 1973 through 1977. For each spill, we know the date and size of the spill, the fraction of oil recovered, spill location, vessel size, and type of oil. Other environmental variables available are inland versus coastal waterways, the affected resources (such as public beaches). Dummy variables were created for these environmental variables, along with a seasonal variable as a proxy for weather. Enforcement is estimated as the number of hours of Coast Guard enforcement per vessel transfer. This varies by district and by quarter. Finally, the Coast Guard maintains a detailed accounting of what caused each spill. From that data, five dummy variables were created to distinguish between intentional and natural causes, as well as equipment failure, personnel error and improper maintenance. Spills of an unknown cause are also included, without being assigned a dummy variable.

In a descriptive analysis of the government's penalty function, Epple and Visscher (1984) viewed the government's problem as a two part decision. They estimated a probit equation for the fraction of spills that were assessed a penalty. Once a penalty was assessed, they estimated its size using OLS. An additional adjustment (which did not significantly alter their results) was made to the OLS model to account for sample selection bias. They found that the penalty increased with vessel size, spill size and the level of enforcement. Table 2 compares various specifications of the penalty function. The first column presents an OLS estimate with the dependent variable being the size of the penalty if it is greater than zero. This corresponds to the Epple-Visscher estimate, and essentially duplicates their results.[32]

Next, proxy variables for the environmental damage and cleanup costs (e.g., type of oil and affected resources), "cause" variables, and the time trend have been added to the equation.[33] This new specification increased the adjusted R^2 from .31 to .35. The third and fourth columns in Table 2 repeat this analysis using a Tobit specification, where the penalty size

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[32] All data in this paper are presented in real dollars, whereas Epple-Visscher used nominal dollars. This probably accounts for the slight difference in the estimated coefficients between column one in Table 2 and column 3 in Epple-Visscher's Table 2.

[33] All of these estimates can be considered reduced form equations, since we do not have data on the probability of detection, damages or cleanup costs. The independent variables used by Epple and Visscher in their estimates partially determine these three variables as well. For example, vessel size probably affects detection; spill size affects detection, damages and cleanup costs; and enforcement affects detection.

TABLE 2

ESTIMATED PENALTY EQUATION

	Penalty > 0 (OLS)		Penalty May Be Zero (TOBIT)	
Constant	-400.62	-183.52	-357.53	252.44
LN [Vessel Size]	36.53 (4.92)*	27.05 (3.61)	25.42 (3.25)	13.26 (1.70)
LN [Spill Size]	209.65 (43.02)	207.46 (42.31)	172.26 (33.89)	169.41 (33.69)
LN [Enforcement]	45.93 (2.75)	39.06 (2.25)	-72.67 (-4.05)	-45.90 (-2.51)
Fraction Cleaned Up		-94.22 (-3.58)		-68.21 (-2.47)
Time		-16.50 (-7.64)		-42.82 (-19.23)
Inland Waterway		-64.57 (-2.35)		-50.11 (-1.73)
Beach		99.49 (0.45)		-122.08 (-0.55)
Crude Oil		9.33 (0.27)		39.41 (1.08)
Gasoline		-86.65 (-2.01)		-34.96 (-0.76)
Distillate Fuel Oil		35.97 (0.61)		47.22 (0.75)
Diesel Oil		-20.88 (-0.58)		-14.93 (-0.39)
Residual Fuel Oil		7.18 (0.22)		26.65 (0.77)
Personnel Error		152.80 (5.81)		135.66 (4.90)
Improper Maintenance		146.04 (2.31)		130.54 (1.96)
Equipment Failure		97.18 (2.94)		62.45 (1.78)
Intentional Discharge		629.08 (9.87)		435.19 (6.72)
Natural Cause		373.50 (1.83)		297.72 (1.40)
Seasonal		-5.58 (-0.75)		-32.52 (-3.17)
R^2	.31	.35		
Log Likelihood			-35254.4	-35019.6
Number of Observations	4241	4241	5103	5103

* t-statistics are reported in parentheses.

is assumed to be truncated at zero. A likelihood ratio test rejected the hypothesis that columns 3 and 4 are identical.

The most important result in Table 2 is that most of the "effort" variables are significant. For example, an intentional discharge of oil will, on average, result in two to four times the penalty for that of an unknown cause.[34]

The only "damage" variable that is significant in both columns 2 and 4 is the fraction cleaned up. Others that are significant in one of the two regressions are inland waterways, gasoline and the seasonal variable. The negative sign for the time trend is consistent with the improved detection technology discussed earlier, if increased detection has a negative effect on the penalty. However, since all monetary variables have been converted to real dollars, it is also possible that the Coast Guard's penalty function has simply not kept up with inflation.

One troubling result is the abiguous sign for the enforcement variable. In the OLS specification it is positive (and significant), while the Tobit regression yields a significant negative sign. The theoretical model developed here suggests that the observed penalty t is a function of the damages, enforcement, level of effort and cleanup costs. Since all spills are required to be cleaned up, all spills are assessed a penalty

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[34] The high coefficient for "natural" causes is not very significant, with a standard error of 217 and a significance level of about 84 percent. This is likely due to the small number of spills reported to be the result of natural causes (15 out of 5,103 spills).

T. For some spills, t = T-C is actually negative, although no monetary penalty is paid by the firm. Hence, the Tobit specification (for censored data) seems appropriate. Note, however, that a Tobit model can be written as a special case of a sample selection model; see Heckman [30]. If a Tobit specification is correct, it can be estimated using Heckman's procedure, although the estimator is not as efficient as maximum likelihood. Although the Tobit specification seems appealing for econometric reasons, and is consistent with the economic model presented here, it is possible that there are other (unobservable) reasons that a sample selection model may be appropriate. For example, the Coast Guard may base its decision on whether or not to assess a penalty on the past performance of the owner of the ship.[35]

Notice that r (the fraction of oil cleaned up), is also an endogenous variable. r is a function of the spill size x, <u>and</u>

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[35] One possible explanation for a positive enforcement variable is that the detection probability and penalty are negatively related. Enforcement may not be a perfect proxy for the probability of detection. For example, it may be that more Coast Guard monitoring resources are needed to sustain a higher penalty, since firms are able to challenge a penalty through Coast Guard administrative proceedings. Knowing this, the Coast Guard may have to spend more time monitoring the firm's action for spills it wishes to penalize heavily, in order to comply with the more stringent burden of proof requirements necessary during administrative proceedings. In disricts with large enough budgets, the Coast Guard may be willing to extract a high penalty even if it means extensive documentation to defend the size of the penalty. In districts that have less budgetary flexibility, they may be more willing to keep the penalty low to lessen the chance of a costly challenge and to reduce the time spent monitoring. This story is consistent with Epple and Visscher's belief that what we are observing is the <u>discretionary</u> enforcement of environmental regulations.

other environmental variables such as wind and water speed, location, weather, and the type of oil. However, the choice of r is independent of the penalty. After r is chosen, and the costs and damages have been tallied, the penalty is assessed. Thus, although the penalty function depends on the endogenous variable r, this two equation system is recursive, and there is no need to use simultaneous estimation procedures.

D. Optimal Penalties and Current Coast Guard Policy

Although the data does not permit us to simultaneously estimate the optimal penalty and the level of monitoring and enforcement, we can examine the current monitoring and enforcement strategy employed by the Coast Guard. A firm's expected penalty for a given spill consists of the probability of detection, cleanup costs and the monetary penalty. The monetary penalty was estimated in Table 2. Estimates of cleanup costs and detection are based primarily on Cohen (1985), which contains a more thorough discussion of the assumptions and techniques used to measure these variables.

The Coast Guard's data base does not have a complete listing of cost of cleanup information. However, the data does indicate for each spill whether or not the recorded cost information is complete. From 1973 through 1981, there were over 600 spills of crude oil reported to have complete cost information. Although this is only a small fraction of the total number of crude oil spills, it does provide some measure of costs.

The cost of cleanup is assumed to be:

$$C(r,x) = a_o[rx]^{a_1} r^{a_2}$$

That is, costs increase with the quantity of oil removed and the fraction of oil removed. The latter assumption is essentially that of diminishing marginal productivity, so that it becomes more costly to remove the last amount of oil. Separate regressions were run for river areas and harbors, since spills that occur in a fast moving waterway are much more difficult (and expensive) to clean up. The following "expected" cleanup cost function can be calculated:[36]

$$C(x) = 120\ x^{.441} + 23\ x^{.707} \qquad (7)$$

The probability of detection can be thought of as consisting of two probabilities. First, the Coast Guard must determine that a spill has occurred. Second, the source of that spill must be detected. The relevant probability for a firm is the product of these two probabilities. The former probability was estimated by Bellantoni and Froehlich (1981) to be 87 percent for all spills over 10,000 gallons. However, since it is likely that the detection rate increases with spill size, and since most spills are less than 10,000 gallons, the true detection rate is probably less than 87 percent. Given that a spill has been detected, the Coast Guard estimates that there is about a 70 percent chance of

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[36] This is based on the regression equations reported in Table 6 of Cohen (1985), columns 1 and 3. A composite estimate was derived using the mean recovery rate and the fraction of oil spilled in rivers versus harbors. Note that this function is based on the <u>total</u> amount of oil spilled, not the amount recovered.

determining the source of the spill.[37] Multiplying these two rates together yields an overall detection probability of about 60 percent.

Table 3 estimates the current "expected" penalty for various spill sizes. The second column is based on column 4 of Table 2, with all other control variables set at their means. Column 3 is the composite cleanup cost function shown in equation (7). Column 4 is thus the total estimated cost to a firm that spills oil and is detected by the Coast Guard.

Finally, column 5 provides an estimate of what the maximum optimal penalty should be, <u>given</u> current levels of monitoring (and detection rate). This is based on an estimated environmental damage of $3.00 per gallon spilled, average recovery rate of 20 percent and detection probability of 60 percent.[38] Thus, if a spill of size x is not cleaned up, it is assumed to do as much damage as the average spill of size 1.25 x (that is cleaned up), or $3.75 per gallon. Adjusting for the probability of detection (dividing by .6), the penalty should be $6.25 per gallon.

The "optimal" penalty estimated in column 5 is subject to a good deal of uncertainty. First, it is biased downwards for very small spills whose detection rate may be less than the 60 percent assumed for this analysis. If small spills have a significantly

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[37] See U.S. Department of Transportation (1983).

[38] See Cohen (1985).

TABLE 3

Estimated Current and Maximum Optimal Penalties for Selected Spill Sizes

Spill Size (gallons)	Current Monetary Penalty +	Cleanup Costs =	Total Penalty	Maximum Optimal Penalty (assumes no cleanup)
5	$132	$316	$448	$31
10	250	449	699	63
50	522	1,041	1,563	313
100	640	1,514	2,154	625
500	772	3,728	4,500	3,125
1,000	1,030	5,575	6,505	6,250
5,000	1,303	14,653	15,956	31,250
10,000	1,420	22,510	23,930	62,500
50,000	1,693	62,736	64,429	312,500
100,000	1,810	98,511	100,321	625,000

Note: All estimates are in 1981 dollars.

lower detection rate, the optimal penalty would have to increase. Second, note that it is based on the estimated environmental damages of a spill that is <u>not</u> cleaned up. Since an optimal enforcement policy would minimize the sum of environmental damages and cleanup costs, the actual penalty (including cleanup costs) must necessarily be less.[39] Thus, there is an offsetting upward bias for all spills to the extent cleanup of some oil can be achieved at an average cost less than $3.75 per gallon.

V. <u>Policy Implications for Oil Spill Enforcement</u>

Based on the maximum optimal penalty estimated in Table 3, many of the smaller oil spills should <u>not</u> be cleaned up at all.[40] For example, a 50 gallon spill is expected to cost a polluter $1,563, even though the maximum optimal penalty <u>without</u> any cleanup is estimated to be $313. This penalty can be broken up into two parts. $187 is compensation for the environmental damage done by the spill. The remaining $126 is an adjutment for the probability of detection. It is clearly a waste of resources to spend over $1,000 to partially clean up a spill that does no

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[39] Unfortunately, we cannot use the cleanup cost function estimated here to determine the optimal cleanup rate and monetary penalty. The cleanup cost function was estimated using data on spills required to be cleaned up by the Coast Guard. Since we do not know if the Coast Guard's cleanup policy is based on a social welfare criteria, it would be inappropriate to use this as an estimate of optimal cleanup rates.

[40] The possibility that small spills may be subject to excessive cleanup was first suggested to me by Robert C. Anderson. The data confirmed his hypothesis.

more than a few hundred dollars in damage if left in the water. Instead, the firm should be fined a monetary penalty of $313 (or less if some cleanup can be undertaken at an average cost of less than $3.75 per gallon).[41]

On the other hand, it is possible that the Coast Guard's penalty is too <u>low</u> for larger spills. Of course, without data on optimal cleanup costs (and ratios), it is not possible to make policy recommendations on the correct penalty size. Nevertheless, the penalties shown in Table 3 suggest that the legal limit of $5,000 per spill may be too low.[42]

Of course, a higher penalty will not be effective if firms have limited liability. Thus, the current liability limits may need to be eliminated if they preclude imposing the proper penalty.[43] Even without the specific oil spill liability limit, a firm may avoid its cleanup responsibility or penalty by either

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[41] Of course, since we may have underestimated the detection rate for small spills, the monetary penalty may need to be larger. But this does not alter the finding about excessive cleanup. Since the total environmental damage ($187) is less than the cleanup cost ($1,041 for a partial cleanup), society is clearly wasting resources on cleanup.

[42] The Coast Guard does have the legal authority to impose up to an additional $25,000 penalty for violating the Port and Safety Act, which could be applied to some oil spills. However, this has not been used as an oil spill penalty and would also be too small a fine for many spills.

[43] Actually, the cleanup liability limit could be rendered superfluous if firms are fully liable for the penalty, since the Coast Guard could always clean up the spill itself and add its cost to the penalty calculation.

declaring bankruptcy or appealing to other maritime liability limit provisions.[44]

One way to avoid the problem of bankruptcy would be to require adequate insurance to cover any Coast Guard penalty. Note that this would not require insurance for unlimited liability (something no insurer would likely provide). Instead, the Coast Guard could establish upper limits on liability based on the size of the oil cargo and the average social cost of a total spill for that vessel size. Recall that it is the *ex ante* incentives of oil transport firms we are trying to affect. Thus, the actual damage caused by a spill is irrelevant for calculating and assessing an optimal penalty.

In an earlier study (Cohen, 1985), I estimated the costs and benefits of current Coast Guard enforcement policy. It was estimated that the benefits of the program exceed its costs, both in the aggregate and at the margin. Assuming marginal benefits of prevention increase with spill volume and marginal costs decrease, this implies that too few resources are being devoted to preventing oil spills.

The findings of this present study suggest that if additional resources are to be devoted to prevent oil spills, they should be directed toward larger spills. Since the current Coast Guard enforcement policy imposes too high a cost on small spills,

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[44] As discussed in Section 4, in the absence the special oil spill liability limits, a ship is only liable for an amount equal to its value.

too many resources are likely being spent on preventing small spills. In addition to shifting emphasis from small to large spills, this study also suggests the Coast Guard should alter its approach to oil spill enforcement.

Since the Coast Guard is located near most oil transfer operations and navigational routes, their mere presence ought to enable them to detect <u>some</u> spills without a separate oil spill monitoring program. In addition, the threat of a criminal penalty may deter some vessel operators from attempting to evade detection. Thus, it is likely that the Coast Guard could <u>decrease</u> their monitoring effort and thereby reduce government expenditures in this area. However, this decreased monitoring would reduce the probability of detection and would require a corresponding <u>increase</u> in penalties beyond that suggested by Table 3.

The regression results reported in Table 1 suggest that even if the penalty function were to remain unchanged, the Coast Guard may be able to obtain the same result by shifting its enforcement effort away from compliance inspections and into port patrols or observing oil transfers.

In Section 3, various alternative assumptions were examined to determine their effect on a government enforcement policy. The issues of limited liability and detection were discussed extensively in this section. Risk aversion is probably not a problem in the case of the oil transportation industry. As mentioned in Section 3, the issues of an uncertain prevention technology and the timing of preventive efforts do not change any of the basic findings presented here.

However, the issue of the principal's utility depending on the size of the penalty raises an interesting problem that could hinder any attempt to implement an optimal penalty scheme for oil spills. There is some evidence that Coast Guard personnel do care about the size of the penalty imposed on firms. Although the law actually requires that a $5,000 penalty be assessed, according to Table 2, about 17 percent of the spills are not assessed a penalty.[45] Furthermore, the average penalty for the 5,103 spills shown in Table 2 is only $510. Since the data was unable to shed much light on why the penalties are so low, we must resort to more casual evidence. Bragaw (1980) suggests that Coast Guard personnel found assessing penalties "was inconsistent with other Coast Guard missions," as they "identified themselves with protecting life and property and preventing disasters."[46] Another related reason may be found in the economic theory of regulation, in which the regulated firm's interests coincide with the regulators.[47]

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[45] Table 2 only includes spills where the source of the spill has been identified. Thus, it excludes those spills where no penalty could be assessed.

[46] Bragaw, 1980, p. 184.

[47] See, for example, Stigler (1971).

Regardless of the underlying reason for the Coast Guard's concern over penalizing firms who spill oil, the theory suggests that this will result in more monitoring and lower penalties than is socially optimal. It appears that this is precisely what we observe.

VI. Conclusion

One lesson to be learned from the analysis in this paper is that issues pertaining to the enforcement of government regulation should not be divorced from discussions about the regulatory policy itself. Improperly designed enforcement programs can lead to (1) a waste of government resources (e.g. monitoring a firm's level of effort when it is unnecessary), (2) a waste of private resources (e.g. cleaning up an oil spill at a cost far in excess of its social damage), as well as (3) less than (or more than) optimal compliance.

The principal-agent framework was shown to be a useful model in which to analyze many issues associated with the enforcement of government regulations. In particular, it allows one to examine when government monitoring efforts have a purposeful role as opposed to being unnecessary and/or socially costly. Viewing a regulated firm as an agent in a principal-agent relationship also has the beneficial effect of forcing the policymaker to design appropriate incentive schemes to ensure compliance.

Throughout this paper, it was assumed the government's objective is to maximize social welfare. However, the goals of government enforcement agencies may differ substantially from a social welfare criteria. Thus, in addition to defining government policy, policymakers should be concerned with the incentives facing enforcement agencies.[48] Otherwise, the most well-intentioned policies are unlikely to be efficiently implemented.

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[48] In Cohen and Rubin (1985), it is argued that many government policies should be implemented by private enforcement agencies, whose compensation is tied to the net social benefits of the regulation.

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