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Agency Problems in Law Enforcement:
Theory and Application to the U.S. Coast Guard

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Abstract

Agency Problems in Law Enforcement: Theory and Application to the U.S. Coast Guard

We study two issues in the enforcement of public law. The first is whether the system of inspections and penalties set by the regulator is effective. The second is whether a better system of inspections and penalties can be designed, given the institutional constraints under which the regulator must function. We study these issues in the context of oil spill prevention activities of the U.S. Coast Guard (USCG), the agency entrusted with the enforcement of maritime pollution laws. A theoretically optimal contract that mixes penalties based on the amount of pollution ex post with penalties based on the extent of non-compliance ex ante is derived. The effectiveness of USCG inspections and penalties in reducing oil spills is then econometrically studied using micro-level data on a panel of US flag tank vessels. Whether the optimal penalty can potentially improve the effectiveness of compliance inspections in reducing oil spills is examined in the light of the empirical results and recent developments in the economics and public management literature on effective incentive contracting. Among our findings is the potential for combining unilateral incentive-based methods with cooperative methods based on reciprocity in order to solve the complex problem of law enforcement.

Keywords: Violations; Optimal Penalty; Micro-Panel Data; Oil Spills; Public Policy.

I. Introduction

The objective of the paper is to study whether law enforcement organizations carry out their activities and policies in accordance with the well-established principal-agent model in the economics and management literature.[1] Do regulatory agencies follow the dictates of these principal-agent models? Enforcement of regulation and laws is a complex activity. Agencies entrusted with this activity must take into account their own budget constraints, institutionally imposed constraints and the distinct nature of firms that they must regulate. Do principal-agent models miss special features that make law enforcement organizations and the laws they enforce fundamentally distinct from each other? In order to answer this question we conduct an organization-level theoretical, empirical, and policy-analytical study of a law enforcement agency.

First, we apply the economic theory of incentive contracting in order to develop the optimal contract between the law enforcement agency and its client firms. This contract answers the question of how an agency can overcome incentive problems due to moral hazard. Second, we empirically study whether organizational level data on enforcement activity and outcomes are in line with the the predictions of this theory.[2] With the theory and empirical results in hand, we provide some anwers to the question of whether economic models oversimplify the law enforcement problem, and whether results from other approaches neglected by incentive-contracting theory may help to better understand why regulators choose the modes of governance that they do.

The specific context in which the theoretical and empirical investigation is carried out is the public enforcement of maritime laws concerning pollution by the U.S. Coast Guard (USCG). One of the USCG's primary organizational goal is the prevention of damage to the marine environment due to oil spills, which the organization strives to achieve through a variety of preventive and investigative enforcement efforts. The focus of the study is on a program concerned with inspections and examinations of US flag vessels known as the Marine Inspection Program. Within this program, our specific interest is in the inspection of tank ships and tank barges, the chief maritime oil polluters.

The USCG is entrusted with enforcing compliance with rules on maritime pollution laid down in

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[1] Beginning with the classic solutions to the principal-agent problem in Ross (1973), Mirrlees (1976), Harris and Raviv (1979), Holmstrom (1979), and Shavell (1979), a large literature has applied those results to number of areas. Some areas of relevance to this study including accounting (Baiman and Demski, 1980), tax compliance (see the references cited in the exhaustive survey by Andreoni, Erard, and Feinstein, 1998), insurance (Holmstrom, 1979), and law enforcement (Polinsky and Shavell, 2000).

[2] Empirical applications in the area of compliance are few in number, and those that are closely linked with theory, even fewer. Epple and Visscher (1984), Cohen (1987), and Helland (1998) are notable exceptions. Cohen (1998) provides an exhaustive survey of theory and empirical contributions to date in the area of monitoring and enforcement of environmental policy.

the Oil Pollution Act of 1990 (OPA90), the Federal Water Pollution Control Act (as amended by OPA90), the Clean Water Act (as amended by OPA90), and international rules on operational and safety standards for vessels in US waters that are codified into U.S. law. Moral hazard and non-contractibility of effort stand in the way of achieving the first best solution to the US Coast Guard's problem of designing a contract with ship owners and ship operators that would elicit optimal effort and expenditure by owners and operators towards maintenance of their ships. This paper examines whether the USCG is able to overcome the incentive problem.

Two pieces of legislation passed by Congress make this study relevant not just for the USCG, but for other government agencies that perform monitoring and regulatory activities similar to the USCG. The Chief Financial Officers Act of 1990 (PL101-576, 1990), and the Government Performance and Results Act of 1993 (PL103-62, 1993) motivated by the need to implement performance-based management across all sectors of the federal government, require agencies to quantitatively measure performance, and to design methods to improve performance. In response to an earlier report by the GAO stating that the USCG had fallen short in its ability to measure its performance,[3] the USCG commissioned a real time database called the Maritime Safety Management System (MSMS) database. This study makes use of this database. The methodology and results in this study provide a framework for the performance evaluation of this particular USCG program. Thus, it is in keeping with performance-based public management in the spirit of Wholey (1999).

Several institutional developments, notably the enactment of OPA90, require that those seminal studies be updated theoretically and empirically. This paper undertakes that task. On the empirical side, this paper extends previous studies of the USCG in the economics literature by Epple and Visscher (1984), Cohen (1987), and Gawande and Wheeler (1999). This paper updates the Gawande-Wheeler study in many ways. First, we develop a deep theoretical framework that enables a clearer view of what constitutes good policy. Second, the new and more reliable data are used here. We use richer panel data that allows variation across units as well as time. Finally, we take our findings into the policy domain.

The paper proceeds as follows. Section II describes the legal and institutional environment within which U.S. Coast Guard enforcement activities are carried out. In Section III a theoretical model of USCG inspections, that takes into account important features of OPA90, is developed. In Section IV the data used in the empirical investigation are described. Section V contains the formal empirical analysis. First, an explicit optimal penalty function from the model is investigated empirically

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[3] Document GAO/RCED-90-132 "Coast Guard Organization and Funding" (July, 1990).

to see whether actual USCG penalties imposed when a spill occurs are in accordance with theory. Second, reduced form equations from the theoretical model are used to infer whether USCG compliance inspections are effective in preventing spills, using aggregate data as well as micro-level data. In Section VI we consider whether policy implications that follow from the empirical findings are feasible, in light of new developments in the applied incentive contracting literature. Concluding observations are made in the section VII.

II. Background: Maritime Law and the US Coast Guard

It is appropriate to begin with an event of national significance in 1989 that led to major modifications in the prevailing environmental statutes. The US flag tank ship Exxon Valdez ran hard aground on a reef off the coast of Alaska spilling 11 million gallons of oil into the pristine and sensitive ecosystem of Prince Williams Sound, the largest spill in U. S. history. The spill spread over 3000 square miles and onto 300 miles of shoreline, contaminating a national park, four national wildlife refuges, three national state parks, four critical habitat areas, and a state game sanctuary. The toll on marine wildlife was substantial. Exxon settled with the state of Alaska and the U.S. government in 1991 for approximately one billion dollars, and spent an additional two billion dollars on cleanup. Private claimants were awarded a further five billion dollars by a jury in 1994, an award that is still on appeal. The damage may have been far worse, given the state of unpreparedness to deal with a spill of this magnitude. The vessel spilled only 20% of its 53 million gallon cargo of crude.

In the wake of the Exxon Valdez incident, the Oil Pollution Act of 1990 (OPA90) mandated explicit liability standards for spills, and amended provisions relating to marine spills in a host of related laws. Companies now bore the ultimate responsibilities for their actions. Government agencies, primarily the U.S. Coast Guard, were charged with a more direct role in preventing spills from occurring, and mitigating spills once they occurred.[4] OPA90 resulted in over forty Coast Guard rulemaking changes designed to "break" the chain of events leading to a spill.

Incidents in foreign waters have served to bring governments together in a coordinated effort to reduce spills worldwide. The Torrey Canyon disaster of 1967 off the coast of Scotland with a spill size that exceeded that of the Exxon Valdez, raised questions about internationally accepted actions that a state could take against foreign vessels on the high seas (i.e. not its territorial waters). As a result, international coordination on maritime law enforcement led to the codification of major elements of MARPOL, the international convention governing the prevention of pollution from ships, into national statutes. The US Congress enacted a suite of laws to implement MARPOL, laying

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[4] The authorities of the Coast Guard are established in the statutes 14 U.S.C. 2, 89, and 141.

down standards for shipping, stowing, and transferring pollutant cargo, regardless of country flag.[5] The U. S. Coast Guard is entrusted with their enforcement.

From the Coast Guard organization's perspective, these are not the only changes that were of significance. In an era of budget cutting, in 1993 Congress enacted the Government Performance and Results Act (GPRA). The Act required every federal agency to develop 5-year strategic plans, identify the agency's long-term strategic goals, and describe how the agency intended to achieve those goals. The Office of Management and Budget was required to evaluate the performance of agencies relative to their performance goals while assessing their budgetary allocations every cycle (GAO/GGD-96-118: Government Performance and Results Act Page 48). Faced with stationary or declining allocations in real terms, it has forced government agencies to control bureaucratic bloat and promote internal efficiency.

The total Coast Guard budgetary allocations are approximately five billion (1997) dollars. Of the total operating budget, around 30% is spent on the marine inspections program with which this study is concerned (its other functions are drug interdiction, immigration, aids to navigation, search and rescue, and USCG reserve). Most marine inspection program expenditures are devoted to compliance and safety inspections on U. S. and foreign flag vessels, with a view to preventing personnel casualties and pollution incidents. In this paper we consider only deep-draft (over 100 tons) U.S. flag vessels.[6] Inspections of U. S. flag deep draft vessels are organized around three sets of activities (a) cargo handling and pollution control, (b) hull activities, and (c) documents, human factors, navigation, and fire fighting. A complete dry-dock or underwater hull inspection is required of all U.S. flag deep-draft vessels about every two years; certificates of inspections or reinspections are issued once every two years; and an annual exam is required. These inspections are designed to uncover violations from standards of safety explicitly detailed in the Coast Guard's Marine Safety Manual. Usually no fine is imposed upon detecting first-time violations. The vessel is expected to be free of the deficiencies noted, by the time of its next inspection.

The main question addressed in the paper is whether there is evidence that the US Coast Guard effectively uses its resources to lower the number of pollution incidents. In the context of maritime pollution, the economic theory of deterrence since Becker (1968) and Stigler (1970) holds that the optimal level of enforcement resources occurs at the level at which the marginal dollar spent on preventing (probabilistic) pollution due to under-maintenance of a vessel equals the cost to the party

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[5] The US is also signatory to international safety of life at sea, or SOLAS, conventions.

[6] The analysis of deep draft Foreign flag vessels is the subject of a companion study.

of undertaking the corrective action to prevent the (probabilistic) pollution. The first step in the analysis is to construct a simple theoretical model which makes explicit the Becker-Stigler mechanism. We next extend the analysis to take into account the real world with institutional constraints.

III. Theory

The seminal studies of USCG inspections and monitoring of oil spills by Epple and Visscher (1984) and Cohen (1987), provide the baseline model for this study. The Epple-Visscher-Cohen model focuses on detection of pollution incidents after they occur and is appropriate for their study of oil spills during ship-to-shore transfers during which USCG resources are expended, even after spills occur, in order to find the responsible party. Our interest is in examining both onshore and offshore spills, and the model we propose is motivated by the fact that both kinds of resources are expended by the USCG, ex ante inspections of tankers and barges to prevent spills, as well as ex post detections or investigations after spills occur. For example, a substantial fraction of USCG resources are spent on ex ante inspections of large tankers that transport crude oil. We therefore extend the Epple-Visscher-Cohen model to take account of both types of inspections and the contracts they imply. Given the legal institutions, notably OPA90, the model develops theoretically optimal contracts and, more importantly, indicates whether and how existing contracts may be improved. To our knowledge this is the first study to develop contracting based on both ex ante and ex post investigations.

The USCG must allocate resources internally to solve two problems. The first is the enforcement of ex ante compliance by a vessel with MARPOL and other laws concerning cargo handling, stowing and shipping, and shipping safety standards enacted in OPA90. The second is the ex post detection and penalizing of pollution occurrences.[7] The level of effort e (measured in dollars, as are all other monetary variables) by the vessel owner is private information, and not observed by the Coast Guard.[8] Oil pollution x by the vessel is a stochastic externality with cumulative distribution function (cdf) $F(x|e)$, where e acts to shift the distribution: $F(x|e_1) < F(x|e_2)$ if $e_2 > e_1$. Higher

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[7] In order to keep the model's focus simple, we will not consider a third problem: (iii) monitoring the firm's level of effort, upon detection of pollution, in order to ascertain fault. In order to decide whether the vessel owner was negligent, the USCG may expend resources m_3 ex post to determine fault, where such expenditures perfectly reveal e. This would be a potentially important issue if our focus were to distinguish between optimal penalties on the basis of strict liability versus fault-based liability (e.g. Kaplow and Shavell, 1994). For example, OPA90 liability limits apply only if there was no negligence nor wilful violation of laws. The considerable damages paid by Exxon were exceptional *because* negligence was established. It was determined that Exxon did not provide a fresh and well-rested crew for the last leg of its journey, and physical exhaustion was a factor in the accident. This paper abstracts from the issue of strict liability versus fault-based liability.

[8] Only ex ante effort is considered, that is, no effort is expended once a pollution incident occurs, for example, to escape detection.

effort level lowers the probability that pollution exceeds x. The cdf $F(x|e)$ is associated with the pdf $f(x|e)$. We assume that both the USCG and ship owners are risk-neutral. This is a modeling convenience and we indicate where the risk aversion on the part of ship owners changes the results significantly.

In anticipation of the empirical analysis, it is useful to define two measures of pollution x. The first measure of x is the size of the spill in gallons of oil spilled per year. This measure is useful if the focus is on controlling spill size. The second measure of x is the number of pollution incidents per year, regardless of their size. This measure is useful if it is believed that controlling the number of spills also controls the number of large spills, a reasonable assertion ex ante. The latter measure is also associated with “time to failure” or duration between an inspection and a pollution incident, which may independently be important. Both on-sea as well as on-shore spills, that occur during ship-to-shore transfers of oil, are included in the analysis. We first describe the Epple-Visscher-Cohen model of ex post detection, then develop the optimal contract with ex ante inspections alone. The important results is the optimal contract when both types of inspections occur, and how legal institutions shape such a contract.

A. Ex Post (Harm-Based) Detection Only

Suppose first, that there is no ex ante inspection, only ex post detection of pollution incidents, similar to police activities to deter crime. If the vessel purposefully or accidentally discharges x gallons of oil, the probability it will be detected is $P_D(x, m_1)$, where m_1 is the resources expended by the Coast Guard in detection.[9] If detected, the vessel is charged a penalty $T_D(x)$. Additionally, the vessel incurs private loss $l(x)$, for example the value of the oil lost, but the analysis is unchanged with or without it so we presume $l(x) = 0$ (see fn. 11).

Assuming risk-neutrality on the part of the vessel owner (agent), he will choose e to maximize expected profit:

$$E\pi(e) = -\int_x P_D(x, m_1).T_D(x) f(x|e) dx - e, \tag{1}$$

where $P_D(x, m_1).T_D(x)$ is the expected penalty given pollution x. The integral term is the expected

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[9] For on-sea incidents $P_D(x, m_1)$ while positive, is low mainly because ex post monitoring m_1 is low. It is not cost effective to track the route of each tank ship to detect pollution in the outer continental shelf (extending up to 200 miles from the coast). Even if that were done, it would be difficult to detect all but spills of several thousand gallons, given the detection technology. For on-shore incidents during oil transfers, $P_D(x, m_1)$ is higher because monitoring resources can used be more efficiently.

private cost of pollution given effort e. The social welfare maximizing government (principal), cognizant of the fact that vessel owners maximize (1), chooses the function $T_D(x)$ to maximize its expected welfare:

$$EW(e, m_1) = -\int_x [D(x) + C(x)] f(x|e) dx - e - m_1, \tag{2}$$

where $D(x)$ is the pollution damage function, and $C(x)$ is the cleanup or recovery cost function.[10] The integral term is thus the expected social cost of pollution given effort e. The remaining terms in (2) are the enforcement costs of ex post detection m_1, and the vessel owner's effort e. Any penalty paid by the vessel owner to the USCG is considered a transfer and does not represent social cost. The government chooses the schedule of penalties $T_D(x)$ and the level of m_1 to minimize (2) subject to two constraints: (i) the vessel owner's optimal choice of e to maximize (1), and (ii) a participation constraint that his expected profit from use of the vessel exceed a lower bound (say, at which bankruptcy occurs).

If effort were contractible, a first-best solution to the problem would be to set $m_1 = 0$, and choose e to satisfy the first order condition: $-\int_x [D(x) + C(x)] f_e(x|e) dx = 1$. Hence, e is chosen so that the marginal expected social benefit of increasing e by one unit equals its marginal cost (assumed to be one dollar). Even though e is not contractible, an optimal contract (Cohen, 1987) that will induce the first best effort with no monitoring is given by the penalty function[11]

$$T_D(x) = \frac{D(x) + C(x)}{P_D(x, 0)}. \tag{3}$$

With this penalty function the social optimum may be achieved without expending any resources towards detection so long as $P_D(x, 0) > 0$. The penalty function is obtained as the solution for

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[10] The social welfare function in (2) presumes that all pollution is cleaned up, which may not be socially optimal if the cleanup technology is expensive. Cohen (1987) considers the case in which a fraction $r \leq 1$ of the spill is cleaned up, where r is the government's decision variable whose choice is a function of cleanup technology and damage function. Then the social welfare function is written as:

$$EW(e, m_1, r) = -\int_x \{D[(1 - r)x] + C(rx)\} f(x|e) dx - e - m_1, \qquad (2)'$$

where $D[(1 - r)x]$ is the damage function, and $C(rx)$ the cleanup or recovery cost. The analysis based on $(2)'$ is essentially the same except for the divergence between cost per gallon spilled and cost per gallon lost, which must be taken into account while estimating the costs of spills.

[11] If $r > 0$ (see previous fn.) the USCG maximizes $-\int_x \{D[(1-r)x] + C(rx)\} f_e(x|e) = 1$. The optimal contract (Cohen, 1987) that will induce the first best effort with no monitoring is given by $T_D(x) = \{D[(1-r)x] + C(rx)\}/P_D(x, 0)$. The government also choose the recovery rate r by setting the marginal damage cost equal to marginal cleanup cost, that is, according to $D' = C'$. The government's choice of r does not affect the vessel owner's choice of e.

$T_D(x)$ when (1) is set equal to (2), with $m_1 = 0$ in (2). Then, maximizing (1) is equivalent to maximizing (2) with $m_1 = 0$: substituting (3) into (1) yields (2) with $m_1 = 0$. The optimal penalty function equates the penalty, if the polluting vessel is detected, to environmental damage plus cleanup cost scaled by the probability of detection. Where $P_D(x, 0) > 0$ is not a viable assumption, for example if x is small, a positive level of ex post monitoring m_1 is desirable.[12]

Where the probability of detection is low, the optimal penalty in (3), once detected, far exceeds the actual social cost. This is precisely when deterrence is most effective. In order to induce vessel owners to take the socially optimal level of care of their vessels penalties increase as the probability of detection decreases. This is basically a restatement, in the context of the USCG, of the well known result on deterrence due to Becker (1968). Note that the result derives in part because the model is of a one-shot game. In repeated games, where the regulator continually interacts with the regulated firm, other solutions are perhaps possible. One such solution may be higher penaltis for repeat violators. Yet another is a more cooperative form of regulation. We examine these possibilities upon examining the empirical results in light of the one-shot game model.

If there were no limits to liability, (3) may well be satisfied in practice even for extremely large oil spills. Since large spills are almost certain to be self reported by the vessel captain or crew, discovered by the USCG, or reported by a third party, P_D is close to 1.[13] The penalties paid by the Exxon Valdez ($ 1 bn. toward damage and $2 bn. toward cleanup) then seems in line with (3), presuming the actual penalties correctly reflected social costs. We investigate below if this is true for spills of all sizes.

B. Ex Ante (Act-Based) Inspections Only

Now consider the case where there is no ex post detection, only ex ante compliance via inspections designed to reveal violations of statutes and safety standards. The USCG spends m_2 in resources to ensure ex ante compliance. The inspections technology reveals the number of vio-

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[12] The optimal penalty function with private loss $l(x)$ is exactly the same as (3). The reason is that $l(x)$ enters the expected profit function of the shipowner as well as the government's expected welfare function:

$$E\pi(e) = -\int_x [l(x) + P_D(x, m_1).T_D(x)]f(x|e)dx - e,$$

$$EW(e, m_1) = -\int_x [l(x) + D(x) + C(x)]f(x|e)dx - e - m_1.$$

With $m_1 = 0$, substituting (3) into the expected profit function yields the government's objective function.

[13] For example, Froehlich and Bellatoni (1981) estimate that 87% of all spills greater than 10,000 gallons are detected. Most of these are actually self-reported.

lations v with probability $P_I(v, m_2)$. Unlike the previous case, no inspections reveal no violations, so $P_I(v, 0) = 0$. Further, the inspections technology is characterized by diminishing returns: $\partial P_I(v, m_2)/\partial m_2 > 0, \partial^2 P_I(v, m_2)/\partial^2 m_2 < 0$. The number of violations v depends stochastically on effort e, given by a cdf $G(v|e)$, with $G(v|e_1) < G(v|e_2)$ for $e_2 > e_1$. Better effort leads to greater likelihood of finding lower numbers of violations. The cdf $G(.)$ induces the pdf $g(.)$. Though v is a discrete random variable, it is treated as a continuous random variable for analytic convenience.

Modeling v as stochastic implies that learning about violations does not fully reveal e, which correctly represents the view of USCG field inspectors. The vessel is penalized on the basis of the number of violations detected, according to a penalty function $T_I(v)$. Under risk-neutrality the vessel owner chooses e to maximize expected profit:

$$E\pi(e) = -\int_v P_I(v, m_2).T_I(v)g(v|e)dv - e. \tag{4}$$

The integral term is the expected private cost of violations for effort level e. The government, cognizant of the fact that vessel owners maximize (4), chooses the function $T_I(v)$ to maximize its expected welfare:

$$EW(e, m_2) = -\int_v \left[\int_x [D(x) + C(x)]p(x|v)dx\right] g(v|e)dv - e - m_2, \tag{5}$$

where $D(x)$ and $C(x)$ are the pollution damage and cleanup/recovery cost functions, as before. The new element in (5) is the *predictive* density of x given v, $p(x|v)$, so called because information about v (probabilistically) reveals the condition of the vessel and helps in predicting spills. [14] The predictive density $p(x|v)$ links every value of v with a probability distribution for pollution x. The inner integral term in (5) is the expected social cost from pollution (as a function of effort e) given that ex ante inspections lead to the discovery of v violations. The double integral thus evaluates the unconditional expected social cost of pollution as a function of e. The remaining terms in (5) are the enforcement costs of ex ante inspections m_2, and the vessel owner's effort e. The government chooses $T_I(v)$ and the level of m_2 to minimize (5) subject to two constraints: (i) the vessel owner's

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[14] In order to obtain the predictive density from first principles, e may be considered a "nuisance parameter" and integrated out using a (possibly subjective) density $h(e)$ so that $p(x|v) = \int_e p_m(x|v, e)h(e)de$,where $p_m(x|v, e)$ is the conditional probability of pollution x given v and e. Subscripting the conditional density $p_m(x|v, e)$ by the mnemonic m suggests the use of v as a monitor. $p_m(x|v, e)$ is central to the concept of an imperfect monitor v when contracting may be done on the basis of x and v (see Holmstrom, 1979; or Mas-Colell, Whinston and Green, 1996, p. 487). Integrating out e eliminates dependence of the optimal contract on e. It may be noted that if v is a sufficient statistic for x, then there is no reason to contract on x at all, only on v (Holmstrom, 1979). But since we observe contracting on both x and v, it is probably true that neither is sufficient for the other. See also fn 15.

optimal choice of e that maximizes (4), and (ii) a participation constraint that his expected profits from use of the vessel exceed a lower bound (bankruptcy).

If e were contractible, the first-best solution would be to choose e to equate marginal expected social benefit of increasing e to its marginal cost (one dollar): $-\int_v [\int_x [D(x)+C(x)]p(x|v)dx] g_e(v|e)dv = 1$. Although only v is contractible, not e, a first best solution given by the following optimal penalty function is possible:

$$T_I(v) = \frac{\int_x [D(x) + C(x)]p(x|v)dx}{P_I(v, m_2)} \tag{6}$$

The optimal penalty function (6) equates the penalty, upon the discovery of v violations, to the expected environmental damage plus cleanup cost scaled by the probability of detecting v violations, where expectation in the numerator is taken with respect to the predictive density $p(x|v)$.

In the terminology of Polinsky and Shavell (2000), the penalty in (3) is the optimal "harm-based sanction", and the penalty in (6) the optimal "act-based sanction". Their simple example (Polsinky and Shavell, p.56) clarifies why both sanctions can be used to achieve the social optimum. Consider the choice between act-based sanctions on the basis of committing the unsafe act of storing chemicals in a substandard tank that increases the probability of harm, or harm-based sanctions on the basis of the actual occurrence of harm if the tank ruptures and spills. Suppose the substandard tank has a 10% chance of rupturing whereupon the harm would be \$10 million, or an expected harm from using the tank of \$1 million. If the tank owner is risk neutral and harm-based sanctions are imposed, deterrence is optimal if the expected sanction, given by the actual penalty upon detection multiplied by the probability of detection, equals the harm. From (3), the optimal act-based penalty is at least \$10 million, and much more if it is difficult to detect. If act-based sanctions are imposed, deterrence is optimal if the tank owner faces expected sanctions equal to his use of the substandard tank, or \$1 million.

Although both harm-based and act-based penalties achieve the social optimum, understanding why one may be preferred over the other reveals why a large part of the USCG operating budget is spent on ex ante inspections, and less on ex post detection. Consider the reasons why act-based penalties may be preferred. First, a comparison of (6) with (3) shows that because of the predictive density term in (6), act-based fines need not be as high as harm based penalties to accomplish a given effort e. This is attractive to the government because it relaxes the participation constraint on vessels, which can never lower social welfare. The limits on liabilities enacted under OPA90 were made precisely to take a tough stance on pollution without deterring participation.[15] If every vessel were subject to the optimal penalty according to (3), the possibility of a huge spill may well be sufficient to keep vessels from participating, thus raising costs to the public in excess of what would be socially desirable (say, due to the inability to import from the cheapest source). Second, since act-based penalties need not be as high as harm-based penalties, they are superior when responsible parties are risk averse. Third, it may be easier to determine how well ship owners maintain their vessels well rather than detect a spill, for example, when vessel crew clean out oil tanks in coastal waters.

These reasons explain why inspections may be undertaken. But why inspections occur with such intensity and regularity remains a puzzle, for according to (6), if the maximal penalty is possible, then the minimal possible ex ante inspection expenditure m_2 need be undertaken. In actuality, the opposite is true: $T_I(v)$ is low and m_2 high. One answer to this puzzle lies in institutional constraints on levying high penalties on the basis of v. Then optimality requires expending more m_2 in order to raise $P_I(v, m_2)$, thereby lowering the optimal penalty in (6). Another reason why policy makers may discourage penalties on v is the uncertainty inherent in the predictive density $p(x|v)$. The variance on the optimal penalty may be too high to justify any but the most trivial penalty function. Our attempts to elicit personal probabilities from USCG personnel only confirmed the substantial variance in their personal probabilities about the occurrence of a specific value of x (one million gallons), given a specific value of v (for example, twenty violations). The full set of conditional probabilities would be even less precise.

C. Liability Limits: Both Ex Ante Inspections and Ex Post Detections

There are at least two reasons for why optimal policy may combine both harm-based and act-based sanctions. First, for reasons discussed above, the uncertainty in the predictive density $p(x|v)$ may inhibit the use of ex ante sanctions to deter small and moderate spills, but not ex ante sanctions to

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[15] OPA90 liability limits (Sections 1004 and 1006 of the Act) are broken down by two major components: damage, and removal/cleanup. Damage includes natural resource damage, subsistence use of the damaged resource by claimants who do not own the resources, and loss of earnings or profits suffered by users of the natural resources. For tank ships greater than 3000 tons, damage is limited to a maximum of \$3333 per ton. For tank ships less than 3000 tons, the maximum damage is up to \$2 mn. per incident. For vessels other than tank ships, damage is assessed at the value of \$600 per ton spilled or \$500,000, whichever is greater. Removal costs are assessed at whatever government resources are spent on removal plus up to \$75 mn. for offshore facility (e..g. mobile offshore drilling unit), and up to \$350 mn. for an onshore facility or in a deepwater port. These liability limits are no longer applicable if negligence and wilful misconduct in violation of federal safety standards is discovered to have been responsible for the spill, in which case the penalty may be harsher.

deter large spills. Second, and perhaps more importantly, the limits on institutional liability make it sensible to combine ex post and ex ante sanctions, resulting in a dual structure of penalties: one ex post to oil spill occurrences and implemented under OPA90 either via USCG-instituted or court-instituted penalties for small and intermediate spills, and another ex ante to any spills via compliance inspections and enforcement of safety standards. The philosophy behind OPA90 is to limit liabilities for large spills (see fn 14) in order not to discourage the shipping of oil, while strictly enforcing penalties for small and intermediate spills. Given the institutional limits of the ex post penalty, say, at $\widehat{T_D}$, both penalties may be optimally combined by specifying an ex post(harm-based) penalty schedule $T_D(x)$ for spills of size lower than x_L, where x_L achieves the limit on liabilities, plus an ex ante (act-based) penalty schedule $T_I(v)$, (in addition to $\widehat{T_D}$) designed to deter actions that would lead to spills larger than x_L.

Under risk-neutrality, the optimal penalties emerge as the solution to the following principal-agent problem. The vessel owner chooses effort e to solve:

$$\text{Max } E\pi(e) = -\int_x \{P_D(x,m_1).T_D(x)\}f(x|e)dx - \int_v P_I(v,m_2).T_I(v)g(v|e)dv - e, \tag{7}$$

with the understanding that the output-based penalty has an upper limit. The maximal penalty $\widehat{T_D}$ implies this upper limit on x, denoted x_L, which can be calculated using (3). Solving the constraint explicitly for x_L yields $x_L = T_D^{-1}(\widehat{T_D})$. The optimization problem (7) can now be written without constraints, by breaking up the first integral into two parts, as

$$\begin{aligned} \text{Max } E\pi(e) = & - \int_{x \le x_L} \{P_D(x,m_1).T_D(x)\}f(x|e)dx - \int_{x > x_L} \widehat{T_D} f(x|e)dx \\ & - \int_v P_I(v,m_2).T_I(v)g(v|e)dv - e, \end{aligned} \tag{8}$$

or

$$\begin{aligned} \text{Max } E\pi(e) = & - \int_{x \le x_L} \{P_D(x,m_1).T_D(x)\}f(x|e)dx - \text{Prob}(x > x_L|e) \times \widehat{T_D} \\ & - \int_v P_I(v,m_2).T_I(v)g(v|e)dv - e. \end{aligned} \tag{9}$$

In (9), $\text{Prob}(x > x_L|e)$ is calculated with respect to the density $f(x|e)$.The expected loss to the ship owner from the harm-based penalty equals the expected penalty given that the damage from the spill is lower than the liability limit plus the expected penalty given that the damage from the spill exceeds the liability limit, in which case $\widehat{T_D}$ must also be paid. Since ex ante sanctions based on violations v are possible, the second integral term is the expected loss to the ship owner from such an act-based penalty, just as in (4). We presume that $T_I(v)$ never exceeds $\widehat{T_D}$.

Taking into account the participation and incentive constraints implied by (9) the government now chooses both $T_D(x)$ and $T_I(v)$ to solve the constrained optimization problem:

$$\begin{aligned}\text{Max } EW(e, m_1) = \; & - \int_x \{D(x) + C(x)\} f(x|e) dx \\ & - \int_v \left[\int_x [D(x) + C(x)] p(x|v) dx \right] g(v|e) dv \\ & - e - m_1 - m_2, \\ \text{s.t. } T_D(x) < \widehat{T_D}. & \end{aligned} \tag{10}$$

We had earlier argued that if liabilities were unlimited, the government would choose only optimal ex post penalties $T_D(x)$ to control oil spills for three reasons. First, the elimination of m_2 (compliance inspections) would result in substantial savings. Second, they would need to spend only minimally on m_1 (ex post detection) – just enough that the probability of detection $P_D(x)$ is positive – and apply (3). Third, act-based are superior to harm-based penalties, due to the uncertainty inherent in the predictive density $p(x|v)$. In sum, with unlimited liability the principal-agent problem is essentially the same as in (1) and (2), with (3) as its solution. With liability limits, however, the government additionally resorts to the use of ex ante penalties to prevent damages that exceed what is recoverable by law. It uses the schedule of ex ante penalties $T_I(v)$,in addition to schedule of ex post penalties $T_D(x)$, to limit its expected loss in the event that a spill exceeds x_L. Solving the constraint explicitly for x_L the government's optimization problem (10) can therefore be written without constraints, as

$$\begin{aligned}\text{Max } EW(e, m_1) = \; & - \int_{x \le x_L} \{D(x) + C(x)\} f(x|e) dx \\ & - \int_v \left[\int_{x > x_L} [D(x) + C(x)] p(x|v) dx \right] g(v|e) dv \\ & - e - m_1 - m_2. \end{aligned} \tag{11}$$

In order to intuitively understand the optimal penalties that solve the principal-agent problem with the limit on harm-based liability, we rewrite the government's maximization problem in (11) by explicitly including the transfer of $\widehat{T_D}$ from the ship owner to the government whenever spill size exceeds x_L as:

$$\begin{aligned}
\text{Max } EW(e, m_1) = & - \int_{x \le x_L} \{D(x) + C(x)\} f(x|e) dx \ - \int_{x > x_L} \widehat{T_D} f(x|e) dx \\
& - \int_v \left[\int_{x > x_L} [D(x) + C(x) - \widehat{T_D}] p(x|v) dx \right] g(v|e) dv \\
& - e - m_1 - m_2. \qquad (12)
\end{aligned}$$

We will use (12) in conjunction with (8) to solve for optimal penalties. Intuitively, an additional constraint (limits on liabilities) can never increase the objective function and will result in a solution inferior to the case of unlimited liability. Seeing this formally provides insight into when the constraint is substantive and when it can be overcome. Rewrite (12) as

$$\begin{aligned}
\text{Max } EW(e, m_1) = & - \int_{x \le x_L} \{D(x) + C(x)\} f(x|e) dx \ - \text{Prob}(x > x_L|e) \times \widehat{T_D} \\
& - \int_v \left[\int_{x > x_L} [D(x) + C(x)] p(x|v) dx \right] g(v|e) dv + \text{Prob}(x > x_L|v) \times \widehat{T_D} \\
& - e - m_1 - m_2. \qquad (13)
\end{aligned}$$

(13) makes it obvious that if the predictive density $p(x|v)$ is identical to the conditional density $f(x|e)$, i.e. if the monitor v provides perfect information about e, then a solution that is close to the first-best solution (given in (3)) is possible. This is because (i) $\text{Prob}(x > x_L|e) = \text{Prob}(x > x_L|v)$, since they are computed using identical densities, and (ii) for the same reason, $\int_v \left[\int_{x > x_L} [D(x) + C(x)] p(x|v) dx \right] g(v|e) dv = \int_{x > x_L} \{D(x) + C(x)\} f(x|e) dx$, so that the sum of the two integrals in (13) equals the integral in (2). Essentially, the limit on the liability is no longer a constraint. In the terminology of Holmstrom (1979), v is a sufficient statistic for x with respect to e, and so when x cannot be contracted upon, such as when $x > x_L$, then v may be contracted upon without loss in efficiency. The only difference between such a contract and the first-best contract in (3) is the amount m_2 that must be expended on the monitor. However, to the extent that $p(x|v)$ diverges from $f(x|e)$, the solution will necessarily be less efficient.

In actuality, the difference between $p(x|v)$ and $f(x|e)$ is likely to be substantial, and this drives a wedge between the deterrence that can be accomplished with unlimited liabilities (requiring only $P_D(x)$) and the deterrence that can be accomplished with limited liabilities (requiring a combination of $P_D(x)$ and $P_I(v)$). This is reflected in the government's optimization problem in (12), which is implicitly based on using a harm-based penalty to the extent possible, and then an act-based penalty when it is no longer possible to contract on the amount of harm. The double integral term in (12) thus indicates the expected loss to the government beyond what is recoverable from the harm-based penalty.

The solution to the principal-agent problem given by (8) and (12) results in a penalty contract that combines a harm-based penalty for spills smaller than x_L, and a harm-based plus act-based penalty designed to prevent spills larger than x_L as follows:

$$T_D(x) = \begin{cases} [D(x) + C(x)]/P_D(x,0), & x \leq x_L, \\ \widehat{T_D}, & x > x_L. \end{cases}$$

$$T_I(v) = \frac{\int_{x>x_L}[D(x) + C(x) - \widehat{T_D}]p(x|v)dx}{P_I(v, m_2)}, \quad x > x_L. \tag{14}$$

Substituting (14) into (8) shows that this solution satisfies (12). The optimal penalty therefore uses $T_D(x)$ to the extent possible, and then penalizes using $T_I(v)+\widehat{T_D}$ to deter spills larger than x_L.[16]

The use of (14) to levy act-based penalties, need not make the penalty burdensome. The penalty may be conditioned on the number of violations being in excess of a high predetermined cutoff, since the purpose of the penalty is to deter the larger spills. If x is a positive monotonic function of x, $x = g(v)$, then $T_I(v) > 0$ only if $v > g^{-1}(x_L)$. Further, since $\widehat{T_D}$ is subtracted from the damage calculation in (14) because damages up to that amount are deterred by harm-based penalties, this further reduces the optimal $T_I(v)$. Theoretically, the use of act-based penalties is attractive due to

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[16] Risk aversion on the part of agents present a second rationale for combining both types of sanctions (in different ways than in (14)). In the theoretical development we have presumed risk neutrality, so that the first best is achievable, at least with unlimited liability, even though effort is not contractible. With risk aversion this is no longer the case, even under unlimited liability, and only a second-best solution is possible due to a binding incentive constraint (see e.g. Mas-Colell et al., 1995, Ch. 14). The second-best contract depends on the information content that output x (here pollution) affords about the agent's actions. The more informative is x, the more efficient the risk sharing that is possible. Holmstrom (1979) shows that additional information y from a monitor (subject to a "sufficiency" caveat), however noisy, is welfare enhancing. The reason is that with the monitor the principal is able to make sharper inference about effort e once x is realized, than without the monitor. Hence a contract based on both x and y is Pareto superior to one based on x alone. Consider the joint distribution $p(x, v|e)$ of x and v given a level of effort e. Under risk aversion, since the incentive problem prevents the first-best solution, the monitor is potentially valuable. Holmstrom (1979) shows that so long as x is not a sufficient statistic for the monitor v with respect to e (in which case the monitor provides redundant information about e once x is known), the monitor is valuable. That is, since $p(x, v|e) = f(x|e).p(v|x, e)$, if $p(v|x, e)$ does not depend on e then x is a sufficient statistic for v with respect to e, and any information provided by v is redundant once x is known). If contracting on both x and v is possible and neither is x sufficient for v and nor v sufficient for x, then contracting on both is socially optimal.

the high payoffs (deterring spills of over a million gallons) at a small cost.

IV. Hypotheses and Data

Hypotheses

The rest of the paper is concerned with using the theory to empirically investigate the *effectiveness* of USCG inspections in reducing oil spills. We should carefully distinguish this issue from testing of the theory. A direct test of the theory would be to empirically analyze the validity of (14), that is, to see whether data on penalties are consistent with (14). We can reject this hypothesis without recourse to formal analysis. For one thing, monetary penalties based on violations uncovered during inspections, $T_I(v)$, are non-existent. And penalties based on spills, $T_D(x)$, are too small relative to damage and cleanup costs to be rationalized by high detection probabilities (Cohen, 1987). The point of developing the theory is precisely to show what the USCG *should* do, if its objective were to maximize welfare. If USCG activities are not effective in controlling spills, theory may serve as a guide to better contracting on the basis of penalties. (14) suggests what the optimal contract should look like.

We begin by arguing that the harm-based sanctions, that is, penalties based on spill size, used by the USCG have only deterred small, but not large, spills. Imposition of penalties are made on the basis of the amount spilled, the impact to the environment, the degree of culpability exhibited by the spiller, and the economic impact of the penalty (Weber and Crew, 2000). The penalty system is implemented in each of the 46 Marine Safety Offices located in major shipping ports along the Atlantic, Pacific, and Gulf Coasts, and the Great Lakes and the Mississippi River System. The Captains of the Port can exercise discretion in the amount of penalty to be recommended. While the USCG has the authority to impose criminal penalties, those are rare. Most USCG pollution cases are instituted a civil penalty . The bulk of spill cases have been placed in Category I, which carry a fine limit of $10,000 because the procedures are less burdensome than, say, a Category II or judicial civil penalty case which may drag on for a long period and occupy scarce USCG manpower. Since 1994 the USCG has begun a system of “ticketing” which further lower the cost of imposing penalties. Tickets carry a fine of $100, and may be paid by mail without requiring a hearing.

Cohen’s (1987) study is seminal on the issue of whether USCG penalties have been optimal. Using 1970s data on pollution incidents during ship-to-shore transfers Cohen finds that the USCG over-penalizes small spills and under-penalizes spills greater than 5000 gallons. Weber and Crew (1998) update this study using data from the 1980s. Following the example of Cohen, they estimate a regression model of USCG penalties on the number and size of spills, and arrive at the conclusion that existing penalties do not deter large spills. The analysis by Viladrich-Grau and Groves (1997) of spills across harbors during ship-to-shore oil transfers shows that the expected fines did not affect the frequency of spills. Both studies ascribe their finding to the low level of fines.

If all but small spills are underpenalized, according to theory the USCG can deter only small spills. Moderately sized spills can perhaps be deterred by the threat of enforcement in the courts of penalties legislated in OPA90. However, limits to liability render OPA90 ineffectual for the really large spills that require damage and cleanup compensation in excess of the liability limit.

If harm-based sanctions cannot be optimally imposed by the USCG due to institutional constraint (for example, the OPA90 limits to liability that the courts can impose), then optimal act-based sanctions, that is, penalties based on violations, should be imposed. It is not possible to perform a direct analysis of act-based sanctions due to lack of data. However, there is little evidence, informal or otherwise, to suggest that act-based sanctions are even close to the optimal suggested by (14). The discovery of violations amount to little more than a slap on the wrist. It is expected that the deficiency will be remedied by the time of the next inspection in the majority of cases, and only if a deficiency is repeatedly uncorrected is any action taken. It appears that spills are not effectively deterred by USCG compliance inspections, especially large spills whose deterrence should be the purview of the act-based penalties. If USCG resources spent on uncovering violations were effective in deterring pollution incidents, then private expenditures undertaken by vessel owners to eliminate violations would lower pollution. These corrective expenditures would then eliminate any correlation between violations and (future) spills.

Even so, might not resources devoted to inspections reduce spills on the margin? That is, even in the absence of a penalty based on (14), USCG inspections might still reduce spills. How might activities such as inspections, that are complementary to penalties, succeed by themselves in deterring spills? Note that the theory is based on welfare maximization (which involves costs of damage and cleanup), while the USCG's objective could well be minimization of spills, and not the maximization of welfare. Possibly, the USCG is only interested in minimizing the number of spills or the volume of spills, without regard to costs. It may calculate that doing so is the best way to minimize big spills. Possessing perhaps the best expertise in vessel inspections in the world, the USCG might decide to rely on the ability of its field inspectors to uncover violations and require its correction (ex post to the violation) than penalize the vessel and deter future violations. This might be in line with a more cooperative form of governance that the USCG might be following rather than the hierarchical relationship between the USCG and vessel owners that is implied by the principal-agent model. Thus, the theory we have developed should guide policy only if we can empirically establish that, regardless of USCG objectives, the resources it devotes to reducing spills are ineffective. (i) inspection hours are not beneficial on the margin, and (ii) violations predict oil spills. If inspections hours are beneficial then we must conclude that inspections are effective despite the absence of penalties for violations. And if violations do not predict spills well, then penalties based on violations are of no use in reducing spills anyway. The object of the econometric exercise then is to explore the following two hypotheses.

H1: Inspection hours are beneficial in reducing spills

H2: Violations do not predict oil spills.

The policy implications of these hypotheses are large. If these two hypotheses are both rejected then (i) USCG resources do not influence spills at the margin and (ii) violations predict spills mainly because violations are underpenalized. In that case, if we believe welfare maximization is the right objective for the regulator, then the theory developed should guide optimal policy. Even more importantly, implication for the theoretical model of rejecting these hypotheses is that there may be alternative models of regulation that deserve consideration in the context of the USCG. These implications are discussed in depth subsequent to the empirical analysis.

Data

A unique vessel-level data set is constructed for the purpose of testing the hypotheses developed above. The econometric analysis is focused on a micro-level panel of deep-draft (vessels with over 100 tons of displacement) U.S. flag tank ships and tank barges over the period 1990-98. They were responsible for 35% of oil pollution in U.S. water over this period. Variables pertaining to each tankship are compiled from information in the *Marine Safety Management System* (MSMS) database, a real-time database maintained by the USCG. The MSMS database tracks all deep-draft U.S. flag tank ships and tank barges, recording details of their inspections and any reported pollution incidents.

The history of the MSMS database is of relevance to the micro-level analysis. Marine casualty (MC) data were first organized under a stand-alone database called CASMAIN, where record of pollution incidents was kept since 1973. Unfortunately, the need to integrate the MC data with marine inspections (MI) data and vessel characteristics was not foreseen early on, and the pre-1986

MC and MI data cannot be related to specific vessels. These separate databases were relationally connected as the MSMS database around 1986. Even so, database personnel are not convinced about the integrity of the micro vessel-level MC (pollution) data in the MSMS database before 1990. In sum, reliable micro level data on pollution are available for 1990-1998. Reliable micro level inspections data are available for 1986-98.

USCG enforcement resources are quantifiable as "input" and "output" measures. Hours devoted to ex ante inspections (m_2 in the theoretical model) form the bulk of resources expended and are the direct "input" measure. These compliance inspections result in "output" measured by the number of violations of safety standards. The correlation between ex ante inspection hours and violations is around 0.40 in the micro-level data for tank ships. Not all inspections are compliance inspections designed to uncover violations. For example, inspection hours include hull exams involving either dry-dock or underwater hull testing. Since considerable USCG resources are devoted to ex ante inspections, data on inspection hours and violations are of high quality. These data are used as measures of USCG enforcement effort at detecting and enforcing compliance aimed at preventing oil spills.

There is virtually no data on resources expended on detection (m_1), that can be meaningfully linked with individual vessels. Although the USCG records a number of "mystery" spills, which is evidence of USCG detection as well as third party reporting of spills, in the micro data no inference is possible about m_1. As mentioned above, a pollution incident may result in a legal case after USCG investigations reveal negligence or other conduct which the Coast Guard judges to be deserving of a civil or criminal case. Thus, the number of legal cases serve as proxies for ex post investigations designed to uncover fault. Our model has not addressed fault-based sanctions mainly because USCG-initiated legal cases happen infrequently. Though their occurrence is sparse, to the extent available the number of legal cases (termed m_3) is included in the econometric model to see if they are effective deterrents.

V. Empirical Analysis

USCG Inspections and Pollution: Evidence from Micro Panels

In order to investigate the first hypothesis about the effectiveness of USCG inspections in reducing the quantity of oil spilled and the number of spills, separate analyses for tank ships and tank barges are performed. The two categories of vessels consume significant USCG resources, were explicitly targeted by OPA90 following the tank ship Exxon Valdez, and produce 35% of spills by volume and a majority of the spectacular spills to date. There are 1711 observations on tank ships and 36963 on tank barges. Due to entry and exit of around 5% per year, the panel is unbalanced. Analysis of this panel data must come to grips with the fact that the spill data are noisy. Spills are not high-occurrence events and do not thickly populate the data. A sparse 10% of the sample recorded a spill in 1990, dropping to less than 5% in 1998. Just because the occurrence of spills have declined does not mean that OPA90 has solved the problem of oil spills. It would take just a single large oil spill to bring this issue back into national focus, which is the problem for which this paper seeks a solution.

Ex ante inspection hours expended has been cut from a high of 220 hours per tank ship in 1992 to little over 100 hours in 1998. The residual includes administrative hours, training (of crew) hours, and travel hours. As the numbers of spills has declined, due perhaps to the requirements of OPA90, so have hours. Since we want to make inferences about the effect of hours on spills, a correction for endogeneity for hours is warranted. The real budget devoted to the marine inspections program has been stagnant since 1992. Since the budget is exogenously determined based on appropriations at the congressional level and other strategic decisions at the USCG policy-making level, we use the budget data to instrument out the endogeneity in the inspection hours variable. In addition, regional dummy variables indicating the geographic location of the office where the inspection took place, and the types of inspections undertaken are also used to instrument the hours variable. The first-stage instrumental variables regressions are discussed below.

The decline in hours per vessel has also resulted in a decline in the number of violations found, since the detection (of violations) technology is fairly labor intensive. A less obvious observation, but one that is important from the point of view of endogeneity of violations is that the number of violations, especially after 1993 track the average hours spent investigating a vessel, that is, it is determined by the inspections technology. To the extent that there is endogeneity in hours, which is the case if they respond to declining number of spills, it induces endogeneity in the violations as well. Budget data, regional dummies, and types of inspection data are used to instrument out the endogeneity in the number of violations.

Similar data patterns are in evidence for tank barges as well. The pollution data are sparser than in the case of tank barges. Only 12-15 inspection hours per barge are spent annually due to their large number and smaller size: on average tank barges are about one-tenths the size of tank ships. The inspection technology is similar: about the same number of violations per inspection hour are detected on tank barges as tank ships.

The econometric model we estimate is of the form:

$$x_{it} = \beta_0 + \beta_1 \ln v_{it} + \beta_2 \ln m_{2it} + \beta_3 \ln m_{3it} + Z\zeta_i + u_i + \epsilon_{it}, \tag{15}$$

where x_{it} measures oil spilled by vessel i in year t. Separate analyses for two measures of x is performed, one where x=spill volume in gallons, and the other where x=number of spills. When x is measured as spill volume, the dependent variable is logged. Two measures of based on spill volume are analyzed: (i) ln(x+1), and (ii) ln[(x+1)/ship size], where the latter measure controls for ship size. When x is measured as the number of spills, they are treated as being generated from a Poisson distribution with mean λ_{it}. The Poisson panel regression is modeled via the link function:

$$\ln \lambda_{it} = \beta_0 + \beta_1 \ln v_{it} + \beta_2 \ln m_{2it} + \beta_3 \ln m_{3it} + Z\zeta_i + u_i. \tag{16}$$

To reduce concerns about heterogeneity the number of spills is also modeled using a negative binomial specification. In both (15) and (16), β_1, β_2, and β_3 are elasticities with respect to the expectation of the left hand side variables. Z measures vessel characteristics such as age, whether the vessel travels mostly on ocean routes, whether it has double sided and double bottomed design, and whether it is steam or diesel driven. We estimate a random effects model, where u_i is the group effect with variance σ_u^2, and cross-group covariance equal to zero. The error ϵ_{it} is classical with variance σ_ϵ^2. There is no correlation between ϵ_{it} and u_i.[17]

m_2 is measured by total hours spent on inspections and examinations, v by the number of violations detected during inspections, and m_3 by the number of legal cases initiated by the Coast Guard. Since ships vary in size, the number of inspection hours are expected to vary with the size of the vessel. Tank ships average 28600 tons of gross displacement capacity with a standard deviation of 25000 tons, while tank barges average 1355 tons with a standard deviation of 1810 tons. Total inspection hours are therefore scaled by the vessel's gross displacement tonnage in order to prevent spurious scale effects.

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[17] The choice of random over fixed effects estimation was made on practical grounds. Our data are deep in the cross-sectional dimension but not on the time dimension. This led to some difficulties in the estimation. For tank barges, for example, with a cross section of nearly 4000 vessels across nine years a fixed effects model for the count data was not estimable.

Since the dependent variable is noisy, careful measurement of explanatory variables is necessary. The measures for v, m_2, and m_3 are each summed over the current and past periods, and then logged. The reason for summing over two periods is that inspections are periodic. Approximately, over any two year period more than 80% of the vessels in the sample have been inspected at least once. Alternatively, (logs of) their current and lagged values could be separately included. The problem with this is that the "holes" in those variables due to the periodicity of inspections may yield spurious results. Our choice of summing them was to make the information in the variables "thicker". Experimentation with summing over two lags, or over the current plus two lags yielded similar results. Experimentation with separate current and lagged values yielded weaker quantitative results, but the qualitative inferences were not very different from what we report here.

Table 1 reports the maximum likelihood estimates of the random effects model from the panel of tank ships. In the first two columns x is measured as ln(Spill Size+1) aggregated over the current and past periods, where spill size is measured in gallons. The first column estimates the model without taking into account the endogeneity of m_2 and v. They are measured, respectively, as $\ln[(\text{Hours/Ship size})_t + (\text{Hours/Ship size})_{t-1}]$, and $\ln[(\text{Violations})_t + (\text{Violations})_{t-1}]$. m_3, measured as $\text{Ln}[(\text{Legal})_t + (\text{Legal})_{t-1}]$, is treated as an exogenous variable.

The second column, labeled "IV", instruments for possible endogeneity in m_2 and v via first-stage regressions reported in Table A1. The first-stage regressions include, in addition to the exogenous variables in Table 1, the following instruments, which are measured synchronously with the endogenous variables: program budget for the marine inspections program, the number of times the vessel was inspected for five types inspections (reinspections, certificate of inspection (COI) inspections, hull inspections, administrative inspections and inspections of other types), and three regional dummy variables indicating regions in which the vessels were inspected. Staiger and Stock's (1997) rule of thumb is that in order to remove concerns about the weakness of instruments (which can impart substantial bias to the 2SLS estimates) the first stage F-statistic be greater than 10. While not reported, it is easily satisfied for the first stage models reported in Table A1.

Estimates from the tank ship sample are reported in Table 1. They are remarkably robust across all the three different measures of x and the model specifications estimated. For brevity, we focus the discussion on the variables of interest: m_2 and v. Coast Guard resources spent inspecting tank ships bear little, if any, relationship to oil spills, whether they are measured as spill volume or the number of spills. If hours spent on inspecting a vessel are random then this finding leads us to reject hypothesis H1. That is, inspection hours do not deter spills on the margin. The use of instrumental variables (models labeled IV) does not change the insignificance of m_2. However, as we have indicated, not all inspections my be random. If hours spent on inspecting a vessel are determined by equating the cost of inspections to their benefit (reducing expected pollution) at the margin, then it is possible for the coefficient on m_2 to be statistically insignificant and yet effective. But is this were true then we should not find that the violations uncovered by inspection hours are good spill predictors.

The chief finding in Table 1, however, is that the violations variable is a good predictors of x. Thus, hypothesis H2 is rejected by the tank ship data. This is true regardless of whether x is measured as spill volume or the number of spills. Strikingly, the IV models indicate that instrumenting for v dramatically increases the coefficient on v. The coefficient on v in Model 2 implies that as the number of violations double, spill volume can be expected to increase by 34.2%. When x is measured as oil spills scaled by ship size, the coefficient on v in Model 4 indicates that a doubling of violations can be expected to increase x by 112.2%. The instrumented count data models (Models 6 and 8) also indicate that doubling of violations increases the expected number of oil spills by around 85%. While a positive sign on v cannot be used to argue the sub-optimality of contracting on v, the estimates are too large to ignore the possibility of inefficient contracting. On the issue of feasibility of optimal contracting on v, we examine below alternative arguments for and against the idea of efficient contracting based on v.

Evidence on fault-based penalties, m_3, is statistically insignificant. It is tempting to draw the same conclusions about m_3 as for m_2, namely that insignificance may be indicative of effectiveness. We hesitate to do so since the data on m_3 are far too sparse to offer as reliable inferences as in the case of m_2. It is likely that the insignificance of m_3 is attributable to its small sampling variance.

Table 2 reports results from the random effects panel model for tank barges. The same inferences about m_2 and v from spill data on tank ships are drawn from spill data on tank barges. Just as in the case of tank ships, inspection hours m_2 are largely unrelated to x, especially after instrumenting, and violation v are a good predictor of x. Instrumenting for v causes the coefficient on v to substantially increase. The similarity in the results in Tables 1 and 2 is surprising because the two types of vessels have little in common. Tank barges mostly operate on inland routes, while tank ships are mostly ocean-going vessels; tank barges are much smaller than tank ships; there are far more tank barges than tank ships; and there is far more heterogeneity among tank barges than among tank ships. The similarity in the results for tank ships and tank barges, despite these fundamental differences, must be due to similar USCG policy with respect to inspecting and penalizing the two types of vessels.

Sensitivity Analysis

We performed the Heckman selection correction to the models in Tables 1 and 2, on the grounds that not all spills may be reported. For models of spill volume, this was done by estimating a selection equation using as regressors binary variables measuring whether the vessel was ocean-going, and three regional dummies to measure where it was last inspected. For models of the number of spills, a reporting equation using those regressors was used in conjunction with the Poisson/Negative Binomial models. The results were nearly identical to the uninstrumented regression results in Tables 1 and 2. This is quite consistent with the finding by Froehlich and Bellatoni (1981) that 87% of spills greater than 10,000 gallons are found, usually self-reported.

VI. Public Policy

The rejection of hypotheses H1 and, especially, H2 begs the public policy question of whether the USCG should reconsider the serious use of penalties as dictated by (14). The use of high powered incentives for eliciting better performance has received attention in the economics and management literature. We present three views, two theoretically well developed approaches from the managerial economics literature that take the principal-agent model as given, and an approach that has emerged in the public management literature, and is theoretically based in the context of repeated games.

Baker (1992) and Prendergast (2000) take the principal agent model as given, but since they emphasize different aspects of the model their policy implications differ markedly. In order to understand why high-powered incentives are observed in some managerial situations and not in others, Baker (1992) derives conditions under which incentive contracting is effective even when using a performance measure that is not the same as the principal's objective. In the USCG case, the principal's objective is to reduce the expected value of x but institutional constraints prevent contracting on the basis of x beyond the liability limits under OPA90. Since limits do not deter large spills from occurring, it opens the door to the use of another performance measure, namely the Coast Guard's discovery of violations upon performing compliance inspections of vessels. The main message from Baker's model is that if the performance measure (v) responds to the agent's actions in the same manner as the principal's value (x), a first best contract is possible, even though the vessel owners' effort e is not observable. The higher the correlation between $\partial x/\partial e$ and $\partial v/\partial e$, the higher should be the optimal penalty rate. The intuition is that when this correlation is high, an agent who chooses an effort level on the basis of v will choose to expend a high effort when the productivity of that effort in reducing x is also high, but low effort when the productivity of that effort in reducing x is low.

Does our empirical finding of a strong correlation between x and v, also imply a strong correlation between $\partial x/\partial e$ and $\partial v/\partial e$? It appears that since both x and v are monotonically increasing in e, the strong correlation between x and v will induce a similar correlation in their marginal productivity. Thus, stronger penalties based on v, specifically using (14), are encouraged by Baker's model.[18]

Prendergast (2000), however, urges caution before jumping to hasty conclusions about prescribing contracts that improve upon the ones already in existence. His point is that in addition to induce agents with the right incentives, efficient contracting must also reflect costs and benefits. Principal-agent theory predicts a negative relationship between uncertainty and the output-based incentives, since the greater the risk the more muted are the incentive effects, while lower risk makes high-powered incentives more effective. A message from Prendergast's (1999) survey is that this theoretical prediction has found weak support at best, from the empirical literature on incentive-based compensation schemes. In order to analyze why the evidence is ambivalent, Prendergast (2000) argues that a positive relationship between uncertainty and output-based incentives is quite possible since input monitoring is less effective when output is more uncertain. The observation that the USCG imposes low or no penalties on v is consistent with this view. Contracting on information from monitoring of agent's inputs, i.e. v, will be done in more stable environments, but less so if output is uncertain. Since oil spills are uncertain events, almost all contracting should be done on the basis of x, not v.

The principal-agent model (repeated every period as a one-shot game) implies a hierarchical mode of governance by the USCG where there is no room for bargaining between vessel owners and the USCG. Real-world interactions between the contracting partiesare, however, repeated overtime. Outcomes in past periods have a bearing on the terms of the contract in the current and future periods. In a repeated game setting the exclusive use of penlties to enforce compliance would encourage the use of harsher penalties for repeat offenders. But even though it is in repeated games with vessel owners, the USCG relies intensively on inspections and almost never on harsh penalties.

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[18] The key properties of the predictive density $p(x|v)$ that would allow efficient contracting on the basis of v, that were independently derived and discussed in Section III.B and III.C, are closely related to the issues emphasized by Baker (1992). For example, high uncertainty or low information content in the predictive density may be caused by the low correlation between the two measures. Intuitively, if a regression of x on v does not reduce the conditional variance of x because the regression may not have explanatory power, efficient contracting on v is not possible. But if, as our results show, there is a strong correlation that reduces the variance in x by conditioning on v, there is the possibility of improving upon the present contract.

Under what circumstances is this strategy rational?

One answer that has emerged from the literature in public management indicates that, in addition to the principal-agent model, more cooperative or "horizontal" modes of governance can also be effective. Lynn, Heinrich, and Hill (2001) define public sector governance broadly as "regimes of laws, rules, judicial decisions, and administrative practices that constrain, prescribe, and enable the provision of publicly supported goods and services through formal and informal relationships with agents in the public and private sectors". Governance thus involves any constitutionally legitimate means, both vertical and horizontal, for achieving direction, control, and coordination of individuals or organizational. Kettl (2002) notes that transformations in governance have introduced more horizontal governance - in search of service coordination and integration with nongovernmental partners in service provision - in addition to the traditional hierarchical form of governance.

May (2005) studies the combination of two approaches to governance in the context of regulating water pollution: the traditional government enforcement of mandatory requirements, and the voluntary approach (defined as government calling attention to potential harm and facilitating action to address them). May finds that the traditional approach is clearly the more effective form of regulation. However, he also finds that the cooperative mode of regulation is effective over and above the impact of traditional enforcement. He attributes the effectiveness of traditional methods to "deterrent fears" and of cooperative methods to the "sense of duty to comply". There exists a duality between the two motivations, and this duality provides the foundation for the use of both types of governance. Based upon a survey of homebuilders subject to regulatory enforcement, May (2004) finds that how inspector behave greatly influences how the regulatee responds. Specifically, facilitating actions on the part of the regulator encourages compliance by engendering the sense of obligation to comply. USCG policy of intensive inspections and soft penalties appear to be in line with May's findings. USCG inspections elicit cooperation in that they are designed to point out violations that could cause the potential harm, but without the threat of deterrence recommended by the principal-agent model.

While rigorous theoretical models have yet to be developed in which reciprocity as the glue that binds social contracts of the type described by May can emerge as an equilibrium, the framework of Scholz (1984a, 1984b) holds promise as a basis for formal models. Scholz shows that it is possible to tactically achieve voluntary compliance by (i) reducing the cost for cooperators and increasing them for violators, (ii) setting lower standards for less significant regulations and higher standards where the consequences of violations can be socially costly, and (iii) stringently pursuing repeat violators.

From many vessel owners' point of view, USCG inspections perform the costly function of signaling where improvements need to be made. Precisely because this information is valuable to many vessel owners, they will respond to the cooperative style of regulation pursued by the USCG. Even were reciprocity possible, can it not be made more effective with the threat of penalties which would trigger deterrent fears. Ayers and Braithwaite (1992) espouse the idea of a pragmatic choice between the enforcement and cooperative approaches. But penalties remain a central feature of their mixed approach. If public management is to be performance-based, as Wholey (1999) strongly recommends, it appears that the best policy prescription in the present context is for the USCG to use penalties on the basis of violations v. The empirical findings, particularly the predictability of $x|v$, makes a strong case for such act-based penalties. However, the penalties should be light, and target only *repeated* violations in order to deter vessel owners that violate saftey standards repeatedly.[19] The penalties trigger "deterrent fears" and force compliance by vessel owners who are deliberate shirkers, while vessel owners motivated by "civic duty" are never hurt by penalties because once a violation is pointed out to them they will take the necessary action to correct it.

VII. Conclusion

This paper is concerned with the study of a specific public organization, carefully constructing an organizational level database, incorporating the organization's special problems into an economic model, investigating the effectiveness of the organization's policies, and suggesting how they may be improved. Specifically, we investigate the public enforcement of the Oil Pollution Act of 1990 (OPA90) by the U.S. Coast Guard (USCG), an organization that takes prides in, among other things, its role of keeping U.S. waters safe from oil spills.

We build upon a principal agent model featuring elements of the contracting literature and the literature on the economics of public enforcement of law. The central theoretical contribution, motivated by the observation that the Coast Guard spends a significant part of its marine inspections program budget on compliance inspections, is a model of optimal contracting based on violations found during such inspections. The model incorporates the key fact that OPA90, while stringently enforcing a system of penalties for oil spills, limits liabilities for accidental spills. In the absence of

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[19] While we have not formally derived the optimal act-based penalty in a repeated game setting, we imagine it would be a function of past and current violations, so that the a specific number of current violations is levied stiffer penalties if it is associated with violations in the past. Neither have we examined reciprocity relationships formally in this paper. Developing these results in a repeated game setting should be addressed by future research in order to better understand reciprocity in regulatory relationships.

liability limits, the optimal output-based contract penalizes spills according to the Becker rule. But in the presence of liability limits, it is optimal to combine spill-based penalties to deter spills until the liability limit is reached, with violations-based penalties to deter spills whose damage exceeds liability limits.

Previous studies have found that penalties are sub-optimal for large spills. OPA90 contains a provision on limits to the polluter's liability, provided the polluter was not negligent. Hence, the present system of penalties does not have the ability to deter the largest spills, which pose a serious threat to the environment. The theory indicates that violations-based penalties can effectively fill this lacuna. Micro-panel data on tank ships and tank barges, the two main sources of spills, over 1990-98 indicate a positive sign on violations, evidence that violations *predict* spills well. While a positive sign is not by itself proof of sub-optimal contracting on violations, the large size of the coefficient on violations, especially in the instrumented regressions, cannot be ignored. On the other hand, we also find that the hours expended on inspections are statistically insignificant, which is not inconsistent with the hypothesis that resources are spent optimally to equate costs and benefits at the margin.

What public policy do the results suggest? Due to the potentially large payoff from regulatory success, and based on the incentive contracting literature and the emerging public management literature, we recommend light act-based penalties based on repeated violations. Where vessel owners are motivated by civic duty, violations will be duly rectified, and where they are deliberate offenders, penalties should deter them. If light penalties do not prove deterrent in the long run, strict penalties according to (14) should be then used.

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Table 1: Pollution and USCG Inspections: Panel data, US Flag <u>Tank Ships</u> 1990-1998
ML Estimates: Random Effects, With and Without Endogeneity Corrections

		Ln(Spill Size+1)		Ln[(SpillSize+1)/ Ship Size]		# of Spills (Poisson)		# of Spills (Negative Binomial)	
		1	2 (IV)	3	4 (IV)	5	6(IV)	7	8 (IV)
	constant	0.826	0.471	0.720	0.594	−0.720	−1.900	−0.718	−1.892
		(3.258)	(1.362)	(2.929)	(1.854)	(−2.155)	(−3.716)	(−2.175)	(−3.726)
[m_2]	**ln[(Hours/Ship size)$_t$]**	−0.250	−0.140	0.064	0.093	−0.069	0.290	−0.155	0.179
	+ (Hours/Ship size)$_{t-1}$]	(−1.646)	(−0.309)	(0.456)	(0.289)	(−0.246)	(0.354)	(−0.548)	(0.217)
[v]	**ln[(# Violations)$_t$**	0.198	0.342	0.067	1.122	0.322	0.838	0.339	0.876
	+ (# Violations)$_{t-1}$]	(7.035)	(7.796)	(4.514)	(4.115)	(5.986)	(7.956)	(6.385)	(8.464)
[m_3]	**ln[(# Legal)$_t$**	0.259	0.159	0.208	0.166	0.234	−0.085	0.159	−0.164
	+ (# Legal)$_{t-1}$]	(0.648)	(0.408)	(0.855)	(0.693)	(0.592)	(−0.236)	(0.405)	(−0.446)
	Age	−0.479	−0.452	−0.191	−0.184	−2.033	−2.148	−1.871	−2.045
		(−1.323)	(−1.277)	(−0.624)	(−0.660)	(−3.386)	(−3.411)	(−3.206)	(−3.285)
	Dummy for	−0.754	−0.757	−0.723	−0.730	−1.167	−1.264	−1.173	−1.312
	Ocean−Going	(−3.359)	(−2.404)	(−3.311)	(−2.452)	(−4.092)	(−2.951)	(−4.171)	(−3.019)
	Dummy for Double	−0.088	−0.025	−0.068	−0.045	−0.226	−0.079	−0.209	−0.078
	Sided	(−1.264)	(−0.366)	(−1.621)	(−1.015)	(−1.521)	(−0.566)	(−1.401)	(−0.559)
	Dummy for	0.113	0.126	0.036	0.040	0.157	0.266	0.172	0.297
	Double−Bottomed	(1.548)	(1.723)	(0.831)	(0.924)	(1.152)	(2.175)	(1.283)	(2.439)
	Dummy for	0.142	0.173	0.066	0.076	0.308	0.388	0.277	0.353
	Steam−Driven	(1.632)	(1.698)	(1.269)	(1.350)	(1.780)	(2.094)	(1.651)	(2.000)
	$\sigma_{randomeff}$	0.201	0.186	0.164	0.163	0.618	0.478	0.693	0.659
		(2.564)	(2.364)	(1.898)	(1.867)	(8.930)	(7.042)	(3.833)	(3.805)
	σ_{var}	1.312	1.312	0.799	0.797	-	-	-	-
		(18.09)	(18.20)	(11.34)	(11.35)				
	N	1711	1711	1711	1711	1711	1711	1711	1711
	Ln *L*	−2916.9	−2908.3	−2074.2	−2070.7	−1202.3	−1172.3	−1188.1	−1159.1

Notes: Random effects (unbalanced) panel estimates. Log-log specification for spill volume (in gallons) and Poisson specification for number of spills. *t*-values in parentheses using White's heteroskedasticity−robust covariance. Ln *L*=maximum log-likelihood. Inspection Hours in '000. Data from MSMS database of USCG. Auxiliary reduced form regressions for fitted values of hours, and inspections use program expenditures in years *t* and *t*−1, number of inspections for each of five different types of inspections in years *t* and *t*−1, primary region where inspections occur (northeast, west, south), and the vessel characteristics in the reported models. See Table A.1 in the appendix.

Table 2: Pollution and USCG Inspections: Panel data, US Flag Tank Barges 1990 - 1998
ML Estimates: Random Effects, With and Without Endogeneity Corrections

		Ln(Spill Size+1)		Ln [(Spill Size+1)/ Ship Size]		# of Spills (Poisson)		# of Spills (Negative Binomial)	
		1	2 (IV)	3	4 (IV)	5	6 (IV)	7	8 (IV)
	constant	0.260	0.207	0.216	0.184	−2.733	−3.060	−2.688	−3.044
		(9.465)	(7.159)	(9.030)	(6.140)	(−32.11)	(−29.85)	(−30.92)	(−29.26)
[m_2]	**ln[(Hours/Ship size)$_t$ + (Hours/Ship size)$_{t-1}$]**	−0.003	−0.104	0.078	−0.059	0.004	−0.270	−0.128	−0.224
		(−0.090)	(−1.355)	(2.660)	(−0.807)	(0.044)	(−0.986)	(−1.183)	(−0.817)
[v]	**ln[(# Violations)$_t$ + (# Violations)$_{t-1}$]**	0.134	0.343	0.112	0.297	0.397	1.220	0.427	1.225
		(13.32)	(16.47)	(12.26)	(15.37)	(15.40)	(20.59)	(16.62)	(20.71)
[m_3]	**ln[(# Legal)$_t$ + (# Legal)$_{t-1}$]**	−0.129	−0.338	−0.102	−0.283	−0.090	−0.891	−0.068	−0.850
		(−1.675)	(−4.256)	(−1.342)	(−3.613)	(−0.435)	(−4.089)	(−0.309)	(−3.729)
	Age	−0.017	−0.117	0.095	0.003	0.020	−0.213	0.106	−0.191
		(−0.265)	(−2.096)	(1.716)	(0.045)	(0.101)	(−1.006)	(0.496)	(−0.886)
	Dummy for Ocean-Going	0.135	−0.006	0.037	−0.090	0.479	−0.058	0.459	−0.056
		(3.970)	(−0.176)	(1.310)	(−2.898)	(6.201)	(−0.687)	(5.989)	(0.652)
	Dummy for Double-Sided	−0.070	−0.068	−0.073	−0.072	−0.216	−0.198	−0.211	−0.191
		(−3.115)	(−3.101)	(−3.462)	(−3.464)	(−3.357)	(−3.341)	(−3.354)	(−3.183)
	Dummy for Double−Bottomed	−0.130	−0.135	−0.117	−0.124	−0.451	−0.428	−0.445	−0.420
		(−8.125)	(−8.566)	(−7.902)	(−8.195)	(−7.264)	(−7.226)	(−7.290)	(−6.990)
	$\sigma_{randomeff}$	0.272	0.267	0.256	0.253	1.001	0.948	0.870	0.677
		(21.056)	(21.11)	(19.93)	(19.79)	(34.74)	(37.01)	(9.574)	(8.379)
	σ_{var}	0.948	0.945	0.905	0.903	−	−	−	−
		(51.36)	(51.60)	(50.94)	(51.13)				
	N	36693	36693	36693	36693	36693	36693	36693	36693
	Ln L	−51254	−51106	−49541	−49419	−12052	−11831	−11949	−11760

Notes: See Notes to Table 1.

Table A1: First-Stage estimates for IV regressions

	TANK SHIPS				TANK BARGES			
	Ln[(Hours/Shipsize)$_t$ +(Hours/Shipsize)$_{t-1}$]		Ln[(# Violations)$_t$ + (# Violations)$_{t-1}$]		ln[(Hours/Shipsize)$_t$ +(Hours/Shipsize)$_{t-1}$]		Ln[(# Violations)$_t$ + (# Violations)$_{t-1}$]	
	Coeff	*t*-value	Coeff	*t*-value	Coeff	*t*-value	Coeff	*t*-value
constant	0.375	5.838	−0.168	−0.619	0.081	6.424	0.167	4.121
Ln[(Program Budget)$_t$ + (Program Budget)$_{t-1}$]	−0.045	−1.182	−0.332	−2.054	0.047	5.936	−0.157	−6.192
Ln[(# Legal)$_t$ + (# Legal)$_{t-1}$]	0.020	0.521	0.382	2.370	0.057	3.729	0.743	15.05
Ln[(# Re-inspections)$_t$ + (# Re-inspections)$_{t-1}$]	0.037	2.205	0.464	6.493	0.028	8.587	0.177	16.77
Ln[(# COI inspections)$_t$ + (# COI inspections)$_{t-1}$]	0.060	2.896	0.700	8.052	−0.060	−15.90	0.119	9.862
Ln[(# Hull inspections)$_t$ + (# Hull inspections)$_{t-1}$]	0.180	12.41	0.186	3.040	0.173	63.56	−0.009	−1.032
Ln[(# Other inspections)$_t$ + (# Other inspections)$_{t-1}$]	−0.004	−0.521	0.776	25.20	0.073	44.21	0.615	116.7
Ln[(# Admn inspections)$_t$ + (# Admn inspections)$_{t-1}$]	−0.027	−3.412	−0.001	−0.027	0.021	9.490	0.124	17.25
Age	0.455	10.75	0.952	5.338	0.025	2.880	0.423	15.05
Dummy for Ocean−Going	−0.275	−10.74	0.640	5.939	−0.131	−34.05	0.282	22.94
Dummy for Double Sided	−0.056	−5.587	−0.005	−0.117	−0.026	−9.602	−0.062	−7.174
Dummy for Double−Bottomed	−0.010	−5.587	−0.212	−5.162	−0.021	−9.090	−0.009	−1.243
Dummy for Steam driven	−0.132	−1.002	−0.297	−6.311	−	−	−	−
Testing Region: Northeast	0.128	−11.79	0.106	1.110	0.059	11.40	0.134	8.043
Testing Region: West	−0.033	5.631	−0.050	−0.586	0.090	16.23	0.111	6.197
Testing Region: South	−0.045	−3.304	0.168	2.914	0.031	11.60	−0.124	−14.282
N	1711		1711		36693		36693	
Adjusted R^2	0.550		0.504		0.175		0.377	

Note: Program Budget=real budget allocated to the Marine Inspection program (data from US Coast Guard); # COI inspections=Number of inspections undertaken for a Certificate of Inspection.