Marine Resource Economics, Vol. 4, pp. 175–192
Printed in the UK.
0738-1360/88 $3.00 + .00

Risk-Sharing and Liability in the Control of Stochastic Externalities

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Abstract *This paper analyzes alternative policies for controlling stochastic externalities, considering both the incentive and the risk-sharing effects of each. When polluter actions are unobservable so that regulation is not possible, alternative liability rules including zero, partial, and full liability are compared. When actions are observable, then regulation is possible, and the use of regulation is compared to the use of liability. The principal-agent paradigm provides the analytical approach used to determine the efficient policy choice. The effect of the availability of insurance is also addressed. This paper concludes with a discussion of the implications of the analysis for the control of stochastic marine pollution.*

Introduction

Many forms of pollution are stochastic in the sense that they result from accidental spills or releases rather than continuous (intentional) emissions. These include the highly publicized problems resulting from spills of hazardous substances during transport by land or sea and the contamination of groundwater supplies by unintentional releases from landfills. Recognition of these forms of stochastic externalities has given rise to questions concerning their control. For example, Just and Zilberman (1979) compare the effects of lump sum taxes and subsidies on a firm's incentive to undertake safety. The control of oil spills through the use of liability rules has been studied by Conrad (1980) and by Opaluch and Grigalunas (1984). A more general treatment of the control of accidents appears in a series of papers by Shavell (1980, 1982, 1984a, 1984b).

The choice of any policy for controlling stochastic externalities generally has two effects: an incentive effect and a risk-sharing effect. The incentive effect provides the impetus for firms to take actions to increase safety and thus reduce the probability of accidents. The risk-sharing effect stems from the fact that the policy choice dictates an allocation of risk, and the amount of risk that parties must bear can have welfare effects. Although the incentive effects of alternative policies have been well-recognized, in general the risk-sharing effects have been ignored. (An exception is Shavell (1982)). However, recent liability cases and their ripple effects suggest that risk may be a very important consideration in decisions regarding activities that could impose substantial externalities. Evidence of this is provided by recent events in the market for liability insurance.[1] Thus,

[1] Large settlements in recent liability cases have caused premiums for liability insurance to increase sharply. In some cases coverage has been eliminated. In response, many firms are reducing or withdrawing the provision of certain goods and services because of the inability to secure liability coverage at a reasonable cost. See the *Wall Street Journal*, January 21, 1986, page 37.

the allocation of risk under alternative policies would appear to be an important factor in the choice of a control policy.

The purpose of this paper is to analyze alternative policies for controlling stochastic externalities in terms of both their incentive and their risk-sharing effects. The policies that are considered depend upon whether the actions of the polluters that affect the probability of a given pollution event are observable or not. When actions are observable, regulation of those actions is possible, and the policies considered include regulation and full liability (i.e. ex post liability for the full amount of damages). However, when actions are unobservable, regulation is not possible. Instead liability rules can be used to induce safety, and we consider alternative rules including zero, partial, and full ex post liability. The paradigm that provides the basis for the analysis is the principal-agent model that is popular in studies of sharecropping, alternative wage contracts, and the organizational structure of firms. The relevance of this model to problems of environmental externalities was first noted by Shavell (1979a).

The paper is organized as follows. In the next section, the pure risk sharing problem (without incentives effects) is presented to provide an understanding of the role of liability rules in the Pareto efficient allocation of risk. The following section presents the model for the case where actions are unobservable and thus incentives for safety must be provided. This section highlights the basic tradeoff between risk-sharing and incentives when polluters are risk averse. The fourth section compares the use of regulation and ex post liability when the polluter's actions are observable (and can thus be regulated). An interim summary of the results is then presented, followed by a discussion of how those results and conclusions would change if private insurance were available to spread risk. Finally, some limitations of the analysis that suggest directions for further research and implications of the analysis for the control of stochastic marine pollution are discussed.

Liability and Risk-Sharing Without Incentive Problems

Embodied in many federal statutes is an attempt to control environmental pollution through imposing strict liability for damages on the responsible parties (Opaluch (1984)).[2] In addition, strict liability is often imposed through state or federal courts under the law of torts. Under strict liability, those responsible for the activity that is causing an environmental problem pay the costs of clean-up and compensation regardless of whether or not they were negligent in their actions. This approach should encourage all parties involved in the generation, transportation, and disposal of polluting substances to take steps to reduce the possibility of environmental damage from their use (Opaluch and Grigalunas (1984)).

[2] Liability is often limited to certain types of costs. For example, liability under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) is limited to clean-up costs, other costs of remedial actions, and damages to public natural resources. In particular, it does not include damages to third parties. Dollar limitations on liability exist under many statutes as well, including CERCLA, the Price Anderson Act (governing nuclear accidents), and several laws governing marine pollution (See final section).

In addition to internalizing the pollution externality,[3] strict liability also implies a particular allocation of risk. Risk arises from the fact that future damages are uncertain and thus are viewed from the present as a random variable. A strict liability rule places the risk associated with the level of future damages on the responsible parties. Although this has advantages in terms of providing proper prevention incentives (see third section), it is not necessarily an optimal allocation of the risk.

The economic assessment of optimal risk-sharing is usually considered within the context of the more general problem of risk-sharing and incentives. This broader problem, embodied in what has generally been referred to as the principal-agent problem, has been studied by many authors, including Stiglitz (1974), Ross (1973), Shavell (1979a), Holmstrom (1979), and Grossman and Hart (1983). The analysis is generally in the context of sharecropping, labor contracts, insurance contracts, or the organizational structure of firms. In addition, Shavell (1979a) discusses its applicability to a comparison of strict liability and negligence standards in controlling stochastic externalities such as oil spills. Leland (1978) and Sutinen (1980) have used a similar model to analyze leasing policies for extractive resources. Our purpose here is to consider the application of the general framework used in this model to the question of risk-sharing for stochastic pollution.

In this context, the model takes the following form. Let c denote the value of damages associated with a future pollution event. From the present perspective, c is viewed as a random variable since future damages are not known. In this discussion of optimal risk-sharing, we assume that the distribution of c is not affected by the actions of the polluter. This assumption is relaxed in the following section where the problem of incentives is considered. Let f(c) be the amount paid by the polluter[4] for damages. The costs that must be borne by the victim (or by the public sector) are equal to c-f(c). Note that if f(c) is constant, i.e. independent of c, then in a legal sense polluters have no ex post "liability" since the amount they pay does not depend on the damages actually incurred. The payment scheme is instead analogous to an ex ante payment to a trust fund to be used for clean-up and compensation. Alternatively, if $f'(c) \neq 0$ then polluters are subject to at least some ex post liability, with $f'(c) = 1$ implying full liability.[5] Thus, the choice of $f'(c)$ determines the allocation of risk between polluters and victims. It is important to note, however, that it does not define the distribution of costs (or, more precisely, expected utility) between the two parties. For any given $f'(c)$, the distribution of costs can be adjusted through changes in an ex ante, i.e. fixed, payment. Thus, even though polluters face no risk under a zero liability rule where $f'(c) = 0$, this does not necessarily mean that they are better off than they would be under a full liability system, since the full liability rule could be accompanied by a smaller fixed payment than the zero liability rule.

[3] See Opaluch (1984) and Shavell (1984a, 1984b) for discussions of some limitations on the use of liability rules to internalize externalities.

[4] We assume that there is a single responsible party to avoid the problem of assigning liability and the potential for free-riding in the multiple polluter case. For a discussion of free-riding in principal-agent models, see Holmstrom (1982) and Segerson (forthcoming).

[5] We use the term "full liability" to refer to a liability rule where polluters must pay the full amount of damages. Throughout the paper, our use of the term liability refers to strict liability, which may or may not be for the full amount of damages.

To determine the efficient liability rule,[6] let $V(v_0 - c + f(c))$ represent the victim's utility function and let $U(u_0 - f(c))$ represent the polluter's utility function, where v_0 and u_0 are the initial wealth levels of the victim and the polluter respectively. Then Pareto optimal risk-sharing is given by a liability rule f that satisfies

$$\max EV(v_0 - c + f(c)) \text{ subj. to } EU(u_0 - f(c)) \geq \overline{U} \tag{1}$$

where $\overline{U}$ is the polluter's reservation level of expected utility, given the choice of the utility function U. The first order conditions for the optimal f require that

$$V'(v_0 - c + f(c)) = \lambda U'(u_0 - f(c)) \tag{2}$$

where $\lambda \geq 0$ is the Lagrangian multiplier on the constraint in (1).[7] Equation (2) defines the optimal level of risk-sharing between the victim and the polluter if the associated second order conditions are met.

To see the implications of (2) for the first best liability rule, differentiate (2) with respect to c and solve for f′(c) to get

$$f'(c) = \frac{V''}{V'' + \lambda U''}. \tag{3}$$

This highlights the importance of the second derivatives of the utility functions, which reflect the attitudes toward risk. For example, consider the implications of (3) in the context of the following alternative cases.

Case 1: Risk Averse Victim ($V'' < 0$). Risk Neutral Polluter ($U'' = 0$). In this case, (3) implies that $f'(c) = 1$, and thus $f(c) = c + k$ for some constant k. As noted above, this corresponds to a full liability rule since any increases in damages are borne fully by the polluter. Thus, when the polluter is risk neutral but the victim is not (so that risk is costly to the victim but not to polluters), then full liability results in optimal risk-sharing with the polluter bearing the full risk associated with future damages. Polluters might be expected to be risk-neutral if potential damages are small relative to the operations of the firm. For example, if the polluter is a large, diversified company with many stockholders, it may be able to spread risks sufficiently to justify risk neutral behavior if potential damages are not too large. However, if the victims are individuals who suffer either monetary or serious health effects as a result of contamination, they will not generally be able to spread those risks. In this case, the assumption of risk neutral polluters but risk averse victims seems appropriate.

Case 2: Risk Neutral Victim ($V'' = 0$), Risk Averse Polluter ($U'' < 0$). This

[6] Pareto efficiency is only one possible criterion for choosing a liability rule. Other considerations such as fairness and precedent could be used as well and are probably more frequently used in practice. However, here we limit our consideration to the economic efficiency objective, recognizing that distributional objectives could be handled through adjustments in $\overline{U}$.

[7] Because f is a contingency rule, i.e., it gives the level of liability contingent on a given realization of the random variable c, the first order conditions depend upon realized marginal utilities rather than expected marginal utilities. See Raiffa (1968) for a more detailed discussion.

assumption implies that $f'(c) = 0$ so that $f(c) = k$. In other words, it is optimal in terms of risk-sharing for the polluter to pay a constant amount that is independent of the actual realized damages. Under this rule, polluters have no ex post liability. They are shielded from the uncertainty associated with future damages, and all of the risk is borne by the victim. This is optimal in this case because risk represents a cost to risk averse polluters but not to a risk neutral victim. It might be appropriate to think of victims as risk neutral if individuals are fully compensated by the government for any damages they incur so that the public sector assumes their risk, and the public sector can spread risks sufficiently across taxpayers (Arrow and Lind (1970)).[8] Risk aversion on the part of polluters might be appropriate if potential damages borne by an individual firm are very large.

Case 3: Both Victim and Polluter are Risk Averse ($V'' < 0$, $U'' < 0$). In this case, $0 < f'(c) < 1$. This implies that $f(c) \neq c+k$ and $f(c) \neq k$. In other words, neither the polluter nor the victim bears the full risk. Instead, risk is shared between them. The polluter is liable for some portion of realized costs, but he is not fully responsible for incremental changes in c. Of course, the optimal allocation of the risk between the two risk averse parties will depend upon the relative magnitudes of U'' and V''. In the special case where both U and V are quadratic, a fixed apportionment scheme ($f'(c) = \alpha$ for some constant α) is efficient, i.e., each party's ex post payment should be a fixed proportion of the damages regardless of the level of those damages. Under more general utility functions, however, the efficient apportionment will depend on the level of damages.

Case 4: Both the Victim and Polluter are Risk Neutral ($V'' = U'' = 0$). In this case, a unique optimal risk-sharing rule does not exist. Since risk does not represent a cost to either the polluter or the victim, the allocation of risk does not have any welfare effects.

In summary, the pareto optimal rule for allocating risk between the victim and the polluter (in the absence of incentive problems) depends upon their risk attitudes. A full liability rule will yield optimal risk-sharing if polluters are risk neutral but not if they are risk averse. Risk aversion by polluters implies that, ceteris paribus, the victim should bear some (if he is also risk averse) or all (if he is risk neutral) of the risk associated with the level of future damages.[9]

Liability and Risk-Sharing with Incentive Problems

The above analysis assumes that the distribution of the random variable representing damages is not affected by the actions of polluters, and thus the only issue of concern is the allocation of risk. In reality, the behavior of polluters can often affect the probability of a given magnitude of damages. The appropriate policy response to this effect depends on whether the preventive actions are observable by the regulatory agency. If those actions are observable and can be monitored

[8] See Fisher (1973) for some limitations to the Arrow and Lind argument.

[9] Note that, if the public can be viewed as risk neutral but individuals are risk averse, then this result is exactly opposite of the current situation under CERCLA. CERCLA holds firms liable for damages incurred by the public sector, thus shielding the possibly risk neutral public from risk. However, damages to private property or individual health or welfare are not covered, thus exposing risk averse individuals to substantial risk unless they are able to obtain compensation under common law. I am grateful to an anonymous referee for noting this apparent contradiction.

(and thus non-compliance detected), then direct regulation is possible. When preventive care cannot be easily monitored, then direct regulation is not possible, but an indirect incentive mechanism such as a liability rule can be used to induce a certain level of abatement or care. In this section, the above analysis is modified to include the need to induce firms to undertake safety measures when direct monitoring is not possible. In the following section, the possibility of using direct regulation is considered.

Let a be the level of safety or preventive care taken by the polluter and let g(c,a) be the probability density function of damages given a.[10] In this case, the Pareto efficient payment scheme is given by the solution to

$$\max_{\{a,f(\cdot)\}} EV(v_0 - c + f(c)) \tag{4a}$$

$$\text{subject to } EU(u_0 - a - f(c)) \geq \overline{U} \tag{4b}$$

$$EU_a = 0 \tag{4c}$$

where the second constraint states that the polluter chooses the level of a that maximizes his expected utility. This constraint reflects the need to motivate the polluter to undertake abatement. This problem can be written more explicitly as

$$\max_{\{a,f\}} \int V(v_0 - c + f(c))g(c,a)dc \tag{5a}$$

$$\text{subject to } \int U(u_0 - a - f(c))g(c,a)dc \geq \overline{U} \tag{5b}$$

$$\int [U(u_0 - a - f(c))g_a - U'(u_0 - a - f(c))g(c,a)]dc = 0 \tag{5c}$$

where $g_a = \partial g/\partial a$. The optimal fee schedule must then satisfy the following condition:

$$V' = \lambda U' + \mu[(g_a/g)U' - U''] \tag{6}$$

where μ is the multiplier on the second constraint. As long as $\mu \neq 0$, i.e., there is a need to provide an incentive, this condition differs from the condition for optimal risk-sharing given in (3). In other words, because of the need to motivate polluters indirectly to take care when their actions are not observable, in general the optimal fee schedule will differ from the one that would generate optimal risk-sharing. This makes intuitive sense when one thinks, for example, about the special case of risk averse polluters and risk neutral victims. In this case, optimal risk-sharing would imply that victims bear all of the risk, i.e., that the polluters not be subject to any ex post liability. However, in the absence of any liability (or enforceable regulations), polluters have no incentive to be cautious. Thus, there is a trade-off between risk-sharing and incentives; greater liability implies greater behavioral incentives but also greater risk for polluters.

This trade-off disappears in special cases. For example, when polluters are risk neutral, i.e., $U'' = 0$, one can show that $\mu = 0$, and thus the problem reduces

[10] Note that g may also depend on the safety decisions of other firms if there are multiple contributors to the potential threat. This would not change the results qualitatively, provided that each firm takes the decisions of all other firms as given.

to one of just optimal risk-sharing. In this case, full liability is optimal, since it provides the correct incentive for precaution while placing all of the risk on the risk neutral party. Likewise, when $g_a = 0$, i.e., when polluters' actions do not influence the probability distribution of c, then again the problem reduces to optimal risk-sharing since polluters will choose a zero level of precaution regardless of the fee schedule.

In general, however, neither full liability nor zero liability (i.e., a fixed payment that is independent of actual damages) is optimal when considering both risk-sharing and incentives. Instead, as long as polluters are risk averse, a system of partial liability is preferred. The extent of that partial liability would depend on the polluter's and victim's risk aversion characteristics and the strength of the incentive effect.

Ex Ante Regulation vs. Ex Post Full Liability

In the previous section, the assumption that the actions of polluters were unobservable implied that direct regulation was not possible, i.e., the fee paid by polluters could not be a function of a. However, if a is observable, then direct regulation is possible. In particular, a fee schedule of the form

$$f(c) = \begin{cases} 0 & \text{if } a \geq a^* \\ \infty & \text{if } a < a^* \end{cases} \tag{7}$$

would be equivalent to requiring the firm to abate a* and then absolving the firm of any liability for actual damages incurred.[11] Thus, the basic framework outlined in the previous section can also be used to compare the use of ex ante regulation and ex post liability in controlling stochastic externalities.

Previous comparisons of these two approaches (e.g., Shavell (1984a, 1984b), White and Wittman (1983), Johnson, Kolstad and Ulen (1986)) have assumed that all parties are risk neutral. They thus focus on the incentive effects of the two alternatives and ignore the risk-sharing effects. In this case the relative desirability of the two approaches depends upon the assumptions that are made about system imperfections. For example, Shavell (1984a) argues that the ability of polluters to escape successful suits or avoid full payment for damages because of asset availability tends to make regulation more desirable, while the inability of regulators to distinguish ex ante among firms threatening different levels of harm tends to favor the use of ex post liability rules. Johnson, Kolstad and Ulen (1986) consider the impact of evidentiary uncertainty, i.e., uncertainty about the legal standard to which a potential polluter would be held in court. In these cases, the inability of the regulation and liability approaches to ensure an efficient level of

[11] The question of whether compliance with regulations issued pursuant to environmental statutes preempts common law used to impose liability is the subject of considerable debate. Some argue that regulatory standards simply provide a minimum set of standards for conduct, while others argue that the creation of a comprehensive regulatory program should be viewed as an attempt by Congress to provide a substitute for common law. The debate was fueled by the 1982 Supreme Court decision in the case of Milwaukee vs. The State of Illinois. (For a discussion of the concerns and issues regarding that decision, see U.S. Senate Hearing 98-247.) Recently, several bills have been introduced in Congress that would significantly reduce the liability of firms that are in compliance with regulations.

precaution stems from some assumed imperfection in the regulatory or legal system. In the absence of these imperfections, the two alternatives would be equally efficient. This result does not hold, however, when the assumption of risk neutrality is relaxed because the allocation of risk under the two approaches becomes a factor in determining their relative desirability. In this section, we demonstrate that even in the absence of system imperfections the two approaches are not equally desirable when risk aversion is allowed.

To simplify the analysis (and make it more comparable with previous work), assume that a pollution event (i.e., a spill or release) either occurs or does not occur and that if it occurs the damages are equal to d. Assume that the actions of the polluter affect the probability that an accident will occur. Thus, the function g(c,a) takes the form

$$c = \begin{array}{l} 0 \text{ with probability } 1 - p(a) \\ d \text{ with probability } p(a). \end{array} \tag{8}$$

where p(a) is the probability of an accident occurring given a precaution or safety level a.

Intuitively, the importance of risk aversion in determining the relative desirability of regulation and full liability can be seen by recalling the well-known fact that risk averse polluters should be willing to pay a premium to eliminate risk. Thus, if compliance with regulations would absolve them of ex post liability, risk averse polluters should be willing to be subjected to a regulatory standard that is more stringent than the level of care they would choose voluntarily under a full liability system. More specifically, let $\tilde{a}$ be the level of precaution that maximizes the polluter's expected utility under full liability, i.e. $\tilde{a}$ maximizes $EU(a) = 1 - p(a))U(u_0 - a) + p(a)U(u_0 - a - d)$. Let $EU(\tilde{a}) = \tilde{U}$ be the firm's maximum expected utility under full liability. The firm should then be indifferent between a full liability system and a policy that couples ex ante payments to victims equal to the expected value of damages under full liability with a regulatory standard of $\tilde{s}$ defined by $\tilde{U} = U(u_0 - p(\tilde{a})d - \tilde{s})$ where compliance with the regulation is a sufficient defense against liability. However, if the firm is risk averse then $\tilde{s} > \tilde{a}$. The differnce $\tilde{s} - \tilde{a}$ is the risk premium the polluter is willing to pay to get rid of the risk borne under full liability. Thus, under regulation the victims can get more prevention for the same "price" (in terms of the polluter's expected utility).[12] However, by choosing regulation over full liability they are also subject to more risk. This risk is costless if they are risk neutral but not if they are risk averse. Thus, which of the two alternatives is preferred depends on how the victim trades off increased risk against increased protection.

To see this more explicitly, consider the Pareto efficient regulatory standard, $\bar{a}$. This is given by the solution to

$$\max_{a,k} EV = (1 - p(a))V(v_0 + k) + p(a)V(v_0 + k - d) \tag{9a}$$

$$\text{subject to } U(u_0 - a - k) \geq \overline{U} \tag{9b}$$

[12] This could be important if policy decisions are made by bargaining in the political arena and polluters have sufficient political clout to prevent the adoption of policies that would reduce their expected utility.

where k is a lump sum transfer from polluters to victims. (If the efficient transfer $\bar{k}$ were negative, the transfer would be from victims to polluters.) This transfer represents an ex ante, i.e., state-independent, compensation or indemnification that keeps the polluter's utility level at $\bar{U}$. Note that, if polluters are absolved of tort liability by compliance with the standard, then under the regulatory approach they bear no risk. All of the risk is borne by the victim. In this sense, regulation is equivalent to a fixed ex ante scheme where the fee is $\bar{a} + \bar{k}$.

Under the alternative policy of imposing full liability without any regulation, firms would be free to choose their level of precaution. Thus, the level of precaution under full liability solves

$$\max_{a} (1 - p(a))U(u_0 - k - a) + p(a)U(u_0 - k - a - d). \tag{10}$$

Note that the solution is a function of k, which we denote a*(k). The level of k necessary to keep the polluter's expected utility at $\bar{U}$ is then implicitly defined by

$$EU = (1 - p(a^*(k)))U(u_0 - k - a^*(k)) + p(a^*(k))U(u_0 - k - a^*(k) - d) \equiv \bar{U}. \tag{11}$$

We denote this solution k* and the corresponding level of precaution $a^* = a^*(k^*)$.

Since the expected utility of polluters has been held at $\bar{U}$ under both policies, we can compare the desirability of the two by comparing the expected utility of victims. Let $\bar{V}$ be the victim's expected utility under the efficient regulatory standard, i.e.,

$$\bar{V} \equiv (1 - p(\bar{a}))V(v_0 + \bar{k}) + p(\bar{a})V(v_0 + \bar{k} - d). \tag{12}$$

and let V* be the victim's expected utility under full liability, i.e.,

$$V^* = V(v_0 + k^*). \tag{13}$$

Then regulation is preferred to full liability if $\bar{V} > V^*$, and vice versa.

Result:

(a) If victims are risk neutral and firms are risk averse, then $\bar{V} > V^*$, i.e., victims are better off under regulation than under a system of full liability;[13] (b) If polluters are risk neutral and victims are risk averse, then $V^* > \bar{V}$, i.e., full

[13] This is consistent with Shavell's (1982) result that, when victims are risk neutral and injurers are risk averse, a first best solution is possible under a negligence standard but not under strict liability. If a firm is only held liable when it is found to have violated the due care standard (assumed known by all), i.e., compliance with the standard implies lack of negligence, then with risk neutral victims the negligence system is equivalent to regulation requiring the due care level of precaution. Note, however, that Shavell compares strict liability and negligence to a first best solution that only requires that a resource constraint be met in terms of expected value, not in each state. Thus, it is not really an ex post transfer problem such as that considered here, i.e. Shavell's first best solution is not the Pareto optimal solution in the absence of incentive problems considered above which implicitly imposes a budget-balancing constraint in each state.

liability is preferred; and (c) Risk neutrality for both parties implies that the two approaches are equally efficient, i.e., $V^* = \overline{V}$.

These results are consistent with what would be expected from the discussion in the previous sections, and they are proven in the appendix. However, when we move away from these special cases and allow both parties to be risk averse, then unambiguous statements about which policy approach is preferred can no longer be made even in the absence of system imperfections. The analysis suggests that something in between full liability and the sole use of regulation, i.e., some form of partial liability plus regulation, would be efficient.

Summary So Far

If system imperfections (such as evidentiary uncertainty, the difficulty of proving responsibility, and limitations on recoverable amounts) are ignored, then the above analysis suggests the following conclusions:

Case 1: Polluters are risk neutral. In this case, both in terms of efficiency and risk-sharing, a system of full liability is efficient. Large firms may be expected to be risk neutral with regard to small risks. However, the recent furor over the shrinking of the pollution liability insurance market suggests that for large environmental risks, firms are not likely to exhibit risk neutrality.

Case 2: Polluters are risk averse, victims are risk neutral, and all of the polluter's precautionary actions are observable. In this case regulation alone would be efficient. The allocation of risk would be efficient, and the correct incentives could be maintained by setting and enforcing an appropriate regulatory standard. However, in reality, it is unlikely that victims of environmental damages will be risk neutral since the losses can be large relative to an individual's income and, even if government compensation for monetary damages is available, there are likely to be non-monetary damages that prevent full compensation. In addition, it is unlikely that all of the polluter's actions that influence the probability of a given magnitude of damages will be able to be controlled through regulations. Even if firms have safety procedures or equipment designed to reduce accidents, the care with which these procedures are followed or the equipment maintained is in general not easily (or cheaply) monitored by the regulatory agency.

Case 3: Polluters are risk averse, victims are risk neutral, and some of the polluter's precautionary actions are not observable. In this case, sole reliance on regulation is not efficient (even though it optimally allocates risk) because it does not provide the correct incentive to undertake unobservable precautionary actions. Instead, it would appear to be preferable to use a system that couples regulation with a liability rule under which polluters are liable for something less than the full amount of damages. Although the use of ex post liability violates optimal risk-sharing, it is necessary to provide some incentive. In general a system of fixed apportionment, i.e., liability for a fixed proportion of damages regardless of their magnitude, is not efficient, although it might be a reasonable approximation to use in practice.

Case 4: Both polluters and victims are risk averse and all of the polluter's precautionary actions are observable. The efficient policy in this case would be similar to that for Case 3, but for different reasons. In general, some combination of regulation and liability would appear to be efficient, where the liability is for an amount less than the full damages. Here the use of liability is not necessary for incentive purposes but rather to reallocate risk, i.e., provide some form of ensured compensation for risk averse victims. The suggested compensation is not full, however, since full compensation would leave risk averse polluters bearing too much risk.

Case 5: Both polluters and victims are risk averse, and some of the polluter's actions are not observable. Again, some form of less than full liability would appear appropriate. If some of the polluter's actions are observable, then coupling the liability system with a regulatory program for those actions would improve the incentive effects without altering its risk-sharing features. This case is perhaps the most likely case for large environmental externalities. It suggests that the joint use of regulation and liability to control stochastic pollution events, such as the combination of the Resource Conservation and Recovery Act (RCRA) and CERCLA to address hazardous waste dangers, is not necessarily redundant. However, the full liability for clean-up costs imposed by CERCLA may place an inefficient amount of risk on polluters if firms are also held liable for the full amount of third party damages under common law.

In each of the above cases, the regulatory or liability policy would in general require a lump-sum, i.e., state independent transfer between victims and polluters in order to maintain an acceptable level of expected utility for one of the parties. (This transfer has been denoted k.) It is an ex ante payment of compensation. When the payment is from polluters to victims (as might be expected under the sole use of regulation or less than full liability), it represents ex ante payment for imposing environmental risks and could take the form of fixed payments to a fund such as Superfund to be used for clean-up of existing problems. Alternatively, when the transfer is from victims to polluters (as might be expected under full liability), it represents ex ante payment for imposing financial risks on firms and could take the form of cost sharing or tax breaks to reduce the financial burden associated with taking substantial precautionary actions.

The Role of Insurance

The analysis in the previous sections implicitly assumes that risk averse parties are unable to transfer risk through the purchase of first party or liability insurance. In this section we discuss how the existence of private insurance markets to spread risk would affect those conclusions. The existence of such markets should not, however, be taken for granted even (or perhaps especially) when risks are very large. For example, in theory under policies that impose risks on polluters (i.e. when $f'(c) \neq 0$), we would expect liability insurance to be available since risk averse polluters would generate a demand for it. Recently, however, the market for liability insurance has nearly collapsed. Thus, although historically they have been able to do so, risk averse polluters may no longer be able to purchase insurance to transfer liability risks, especially those associated with low probability, high consequence (LP-HC) events. Since the availability of insurance affects the allocation of risk under the alternative policies, whether or not it exists is an important factor in analyzing those policies when polluters or victims are risk averse.

The impact of insurance on the efficiency of different liability rules has been studied by Shavell (1982). The discussion here draws on some of Shavell's results and the well-known fact that a risk averse party can improve his welfare by purchasing actuarially fair insurance. We consider in turn the cases summarized in the previous section. Table 1 presents a synopsis of the results.

Case 1: Polluters are risk neutral. In this case, the possibility of purchasing liability insurance is irrelevant since risk neutral polluters would have no incentive to purchase actuarially fair insurance. Full liability is still the efficient approach in terms of both incentives and risk-sharing. Since victims bear no risk under full liability, their ability to purchase first party insurance is also irrelevant.

Case 2: Polluters are risk averse, victims are risk neutral, and the polluter's actions are observable. Again, the availability of insurance does not change the previous conclusions. Regulation alone is still efficient. Victims have no interest in insurance because they are risk neutral, and polluters will not purchase any insurance because they do not bear any risk under regulation.

Case 3: Polluters are risk averse, victims are risk neutral, and some polluters' actions are unobservable. The fact that some actions are unobservable implies that liability insurers will be unable to base premiums on the level of preventive action and as a result moral hazard will exist.[14] Risk averse polluters would be expected to purchase less than full coverage for the risks they must bear (Shavell, 1979b). Shavell (1982) has shown that in this case the efficient liability rule is to either (1) impose full liability on the polluters or (2) prohibit liability insurance and impose an appropriate level of partial liability. The net effect of these two alternatives is the same, since under the first one polluters would purchase less than full coverage, leaving them with the same incentives and risks as under the second option. (The banning of liability insurance under the second option ensures that firms cannot further dilute the incentive effects of partial liability through the purchase of insurance.) In addition, because victims are risk neutral, they are unaffected by the greater risk they bear under the second option.

Case 4: Both polluters and victims are risk averse, and the polluter's actions are observable. It is in this case that the availability of insurance has the greatest potential for improving the outcome since the problem here is only a problem of risk-sharing and not a problem of incentives. In the absence of insurance, efficiency requires that risk be divided between polluters and victims. However, if both first party and liability insurance are available, then both victims and polluters can eliminate their risk through the purchase of insurance, and the allocation of risk becomes irrelevant. If, on the other hand, only liability insurance is available, then the use of full liability is efficient. Polluters will purchase actuarially fair insurance to transfer the risks they bear under full liability, but, since their actions are observable, insurers will base their premiums on those actions and thus firms will still face the proper incentives. Alternatively, if only first party insurance is available, then the use of a regulatory approach without liability shelters polluters from risk, and victims can also avoid risk through the purchase

[14] If accidents occur frequently enough to allow an insurer to distinguish between "cautious" and "careless" firms and firms remain in one category or the other, then experience rating, i.e., basing premiums on the past record of accidents could be used to reduce the moral hazard problem. However, this would imply that polluter actions are essentially observable since they could be inferred from observations on the firm's history of accidents.

Table 1
Summary of Results

Case	1 a	1 b	2 a	2 b	3 a	3 b	4 a	4 b	5 a	5 b
Polluter's Risk Behavior	Neutral	Neutral	Averse	Averse	Averse	Averse	Averse	Averse	Averse	Averse
Victim's Risk Behavior	Either	Either	Neutral	Neutral	Neutral	Neutral	Averse	Averse	Averse	Averse
Polluter's Actions[a]	Either	Either	Obs.	Obs.	Unobs.	Unobs.	Obs.	Obs.	Unobs.	Unobs.
Liability Insurance Available?	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Recommended Policy[b]	Full Liab.	Full Liab.	Reg. without Liab.	Reg. without Liab.	Partial Liab.	Full Liab. or Partial Liab. with ban on Ins.	Reg. with Partial Liab.	Full Liab.[c]	Partial Liab.	Full Liab.[c]

[a] Obs. = observable, Unobs. = unobservable
[b] Liab. = Liability, Reg. = Regulation, Ins. = Insurance
[c] Assuming first party insurance is not available

of insurance. Thus, in this case, the choice of an efficient policy depends crucially on the availability of insurance.

Case 5: Both polluters and victims are risk averse, and some polluter actions are not observable. Here the incentive problems are the same as in Case 3 because of moral hazard. If both victims and polluters are able to transfer risks through the purchase of insurance, then the proposed policies are the same as well, i.e., either full liability or partial liability with a ban on the purchase of liability insurance. However, if risk averse victims cannot purchase first party insurance to cover the risks they would bear under the second option, then the use of full liability is the preferred option. Firms would be expected to purchase partial coverage, which would transfer the risk not borne by polluters from risk averse victims to a (presumably) risk neutral insurer.

Conclusions and Limitations

Recent events regarding legal liability for damages due to stochastic pollution and the associated ''insurance crisis'' suggest that potential polluters exhibit risk aversion with respect to the uncertainty associated with potentially large damages. Furthermore, it seems likely that in most cases of stochastic pollution some of the actions of the potential polluter that affect the probability distribution of damages are not easily subject to regulation. When these two conditions exist, the above analysis suggests the following conclusion: (1) If liability insurance is not available to transfer risks, then an efficient policy for the control of stochastic externalities would include the use of both regulation of observable actions and ex post liability, where the liability would be for an amount less than the full amount of damages; and (2) If liability insurance is available, then the use of full liability is efficient since risk-sharing can be achieved through the purchase of insurance.

There are several caveats to this conclusion that reflect the limitations of the above analysis. First, as noted previously, imperfections in the regulatory and liability systems have not been included in the model. However, the results of Shavell (1948a) and Johnson, Kolstad and Ulen (1986) suggest that inclusion of system imperfections would not necessarily change the conclusion that the joint use of regulation and some ex post liability is desired.

Secondly, although the expected utility model used here is the paradigm used most frequently in economic models of decision-making under uncertainty, it has been the subject of considerable criticism by many economists, social psychologists, and decision analysts.[15] The use of alternative paradigms could lead to different conclusions since the implied perception of risk would be different.

Thirdly, the model used is a short run model that does not capture nonmarginal adjustments by polluters or victims. To the extent that the different policies imply different expected costs for either polluters or victims, in the long run they would be expected to respond accordingly. For example, high expected costs under a full liability policy might cause individual firms to leave the industry. Alternatively, the prospect of large uncompensated damages might cause victims to relocate to areas of lower risk. These non-marginal behavioral responses would have implications for the long run effect of any policy choice.

[15] See Schoemaker (1982) for a survey of issues.

Finally, the static nature of the model,[16] the omission of administrative and legal costs, and the difficulty of empirically determining the risk aversion characteristics of polluters and victims should be kept in mind when interpreting the conclusions of the analysis.

Implications for Control of Marine Pollution

The conclusions from the above discussion have implications for the efficient control of marine pollution. The current approach to controlling stochastic forms of marine pollution employs a combination of regulation and ex post liability for damages due to releases of polluting substances. For example, regulations governing the use of the marine environment for transportation and waste disposal have been promulgated pursuant to a number of federal statutes, including the Ports and Waterways Safety Act, the Clean Water Act, the Coastal Zone Management Act, the Deepwater Port Act, the Marine Protection, Research and Sanctuaries Act, the Outer Continental Shelf Lands Act, and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). Several of these (Clean Water Act, Deepwater Port Act, and CERCLA) explicitly impose liability on vessel or facility owners or operators for clean-up costs and damages to natural resources that result from unauthorized discharges into the marine environment. However, in the absence of gross negligence or willful misconduct, the total amount of the liability is limited to a specified dollar amount.

The results discussed above suggest that this joint use of regulation and liability may be justified if the owners/operators of polluting vessels or facilities can undertake actions that affect the probability of a release occurring but are not easily observable (and thus subject to regulation). In addition, the dollar limits placed on their liability can be viewed as a means of sheltering risk averse polluters from some risk, again a goal that is consistent with the above results. However, limiting risk by putting a dollar cap on liability is not generally an efficient means of risk allocation.

The use of a liability cap is equivalent to publicly-provided insurance with a deductible equal to the amount of the cap. It implies a system of full liability for small damages and partial liability for large damages. Full liability for small damages is efficient in terms of both risk-sharing and incentives if polluters can be considered risk neutral with respect to small damages. As noted above, partial liability for large damages is also efficient if polluters are risk averse with respect to large damages. However, implementing partial liability through a liability cap implies that marginal liability is zero beyond the amount of the cap, i.e., $f'(c) = 0$ for all c in excess of the cap. Since this violates Equation (6), it is not an efficient way to balance risk-sharing and incentive needs. The analysis suggests that a preferred approach would be to hold polluters liable for some percentage of damages once they exceed a certain level. Although theoretically that percentage should not be independent of the magnitude of damages (unless both U and V are quadratic), a constant percentage might be desirable in practice because of its simplicity and the difficulty of determining empirically the precise form of the optimal nonlinear liability rule. Note, however, that if the polluter becomes very

[16] For a discussion of the dynamic nature of the legal system, see Blume and Rubinfeld (1982).

risk averse as damages become very large, then the risk-sharing effects would come to dominate the incentive effects, and the efficient level of marginal liability would approach zero as damages increased. This would imply that at some point a cap on liability might be desirable.

Appendix

1. *Claim*: If $V'' = 0$ and $U'' < 0$ then $\overline{V} > V^*$.
   Proof: If $V'' = 0$, then $V' = \gamma$ for some constant γ and $\overline{V} = \gamma\cdot(v_0 + \overline{k} - p(\overline{a})d)$ under regulation. Thus, since $V^* = \gamma(v_0 + k^*)$, it is sufficient to show that $k^* < \overline{k} - p(\overline{a})d$.
   When $V' = \gamma$, the first order conditions for (9) imply that $p'(\overline{a})d + 1 = 0$ and thus that $\overline{a}$ minimizes $a + p(a)d$. This implies that

$$\overline{a} + p(\overline{a})d \leq a^* + p(a^*)d \rightarrow p(\overline{a})d \leq (a^* - \overline{a}) + p(a^*)d, \\ \rightarrow \overline{k} - p(\overline{a})d \geq \overline{k} - (a^* - \overline{a}) - p(a^*)d. \tag{A1}$$

Furthermore, by strict concavity of U,

$$U[p(a^*)(u_0 - k^* - a^* - d) + (1 - p(a^*))(u_0 - k^* - a^*)] \\ > (1 - p(a^*))U(u_0 - k^* - a^*) + p(a^*)U(u_0 - k^* - a^* - d). \tag{A2}$$

Finally,

$$(1 - p(a^*))U(u_0 - k^* - a^*) \\ + p(a^*)U(u_0 - k^* - a^* - d) = U(u_0 - \overline{k} - \overline{a}) \tag{A3}$$

since both are equal to $\overline{U}$ by (9b) and (11).
Combining (A2) and (A3) yields

$$U[u_0 - k^* - a^* - p(a^*)d] > U(u_0 - \overline{k} - \overline{a}),$$

and thus, assuming U is monotonic,

$$u_0 - k^* - a^* - p(a^*)d > u_0 - \overline{k} - \overline{a} \\ \rightarrow k^* < \overline{k} - (a^* - \overline{a}) - p(a^*)d \leq \overline{k} - p(\overline{a})d$$

where the last inequality follows from (A1). Q.E.D.

2. *Claim*: If $U'' = 0$ and $V'' < 0$, then $V^* > \overline{V}$.
   Proof: If $U'' = 0$, then $U' = \beta$ for some constant β and by (9b) and (11)

$$\beta\cdot(u_0 - \overline{k} - \overline{a}) = \beta\cdot(u_0 - k^* - a^* - p(a^*)d) \rightarrow \overline{k} + \overline{a} = k^* + a^* + p(a^*)d. \\ \rightarrow k^* = \overline{k} - (a^* - \overline{a}) - p(a^*)d. \tag{A4}$$

Furthermore, by strict concavity of V,

$$V[(1 - p(\bar{a}))(v_0 + \bar{k}) + p(\bar{a})(v_0 + \bar{k} - d)] > (1 - p(\bar{a}))V(v_0 + \bar{k}) + p(\bar{a})V(v_0 + \bar{k} - d) = \bar{V} \rightarrow V[V_0 + \bar{k} - p(\bar{a})d] > \bar{V}. \tag{A5}$$

Finally, when $U' = \beta$ then from (10) a^* minimizes $a + p(a)d$

$$\rightarrow a^* + p(a^*)d \leq \bar{a} + p(\bar{a})d$$

$$\rightarrow v_0 + \bar{k} - p(\bar{a})d \leq v_0 + \bar{k} - (a^* - \bar{a}) - p(a^*)d \tag{A6}$$

$$\rightarrow V[v_0 + \bar{k} - (a^* - \bar{a}) - p(a^*)d] \geq V[v_0 + \bar{k} - p(\bar{a})d] > \bar{V} \tag{A7}$$

where the first inequality assumes V is monotonic and the second follows from (A5).

Substituting (A4) into (A7) yields

$$V^* = V[v_0 + k^*] > \bar{V}. \qquad \text{Q.E.D.}$$

Acknowledgment

This paper was presented at the Association of Environmental and Resource Economists' Workshop on Marine Pollution and Environmental Damage Assessment, Narragansett, Rhode Island, June 1986. The author would like to thank two anonymous reviewers for comments. Funding for this research was provided in part by the College of Agriculture and Life Sciences at the University of Wisconsin and the U.S. Geological Survey, Department of the Interior, as authorized by the Water Resources Research Act of 1984.

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