A New Regulatory Tool

William C. Bunting*
Ph.D. Candidate, Yale University
Law and Economics Fellow, NYU School of Law

January 8, 2007

Abstract

Fill in later.

1 Introduction

Shavell (1984) provides a seminal analysis of two distinct, and often encountered, instruments in controlling external risk: ex ante regulation and ex post legal intervention. Three actors are involved: a firm, which undertakes a risky activity that results in harm to third-parties with some positive probability; a regulator, who intervenes ex ante and enforces a verifiable standard of precautionary effort, affecting the probability of an accident; and a judge, who operates within a stict liability legal regime. Shavell shows that optimal regulation implies setting a standard of care such that the firm's marginal disutility is equa to the expected damages. The benefit of strict liability derives friom the possibility of discovering the value of this damage when a legal suit is undertaken and to improve incentives conditional on this event.

Hiriat et al. (2004) extends Shavell (1984) by allowing ex ante regulatory transfers that are socially costly. Hiriart et al. (2004) show that the first-best level of care depends on the level of harm incurred in the event of an accident. When care is observable, the first-best can be easily implemented because the firm's private information does not enter directly into its objective function, but only indirectly through the mechanism offered by the regulator. On the other hand, when care is unobservable, the results are mixed. If the firm is sufficiently wealthy, then the regulator can overcome the moral hazard problem by creating a sufficiently large wedge between transfers in the event of an accident and those made in the event of *no* accident.

When the limited wealth constraint binds, however, the authors prove that ex post legal intervention is useless. The regulator must give the firm a socially

*William C. Bunting is a Fellow in Law and Economics, New York Law School, and a Ph.D. candidate in the Department of Economics at Yale University. Helpful comments were provided by x. The author acknowledges the financial support of the y.

costly liability rent to induce care. The regulator, however, can no longer choose transfers so that adverse selection incentive compatibility constraints are satisfied at no cost, where it is shown that this implies that the same level of rent must be given to the firm, whatever private information it possesses with respect to harm, and that transfers in the event of no accident are independent of harm.

In other words, regulatory transfers are used to induce the firm to internalize the effects of its actions and to partially realign social and private incentives, but do not allow for information revelation. In this context, moral hazard, thus, significantly magnifies the adverse selection problem, leading to socially costly inefficiencies. That is, under moral hazard with respect to precautionary effort and adverse selection with respect to harm, there is no information revelation and ex post legal intervention is useless.

These results present a disheartening conclusion for proponents of ex post legal intervention. The present paper shows that this conclusion is not as troubling as it may, at first, appear for such proponents, in that the magnitude of harm, and not just the probability of harm, is likely to be a function of effort. If this is true, then the regulator can implement a mechanism under which the moral hazard is false; that is, the firm has no real freedom in choosing precautionary effort after agreeing to a specific regulatory contract, which, thus, allows for information revelation with respect to type.[1] In other words, it will be shown that if there exists some functional relationship between type and effort, which is likely to be the case, then ex post intervention remains an important instrument for controlling external risk, albeit not one that ensures the first-best.

In addition, the paper also introduces formally into the model institutional constraints not considered in Hiriart et al. (2004). In particular, the regulator as modelled here is far more constrained in what it can do, reflecting a public skepticism presently towards regulatory intervention, the principal such constraint being that the regulator cannot impose punishments. Only the judge can punish. The regulator can, however, relieve firms from such legal liability, provided the firm complies with a particular regulatory standard of care. The regulator can make positive transfers to firms, but, similarly, it is assumed that it is socially costly for the regulator to do so.

Furthermore, the court operates under a strict liability regime where no punitive damages allowed. That is, the punishment imposed by the court must be equal to the harm incurred by the victim. As opposed to Hiriart et al. (2004), there is no variability allowed in the magnitude of the sanction, where, typically, the optimal sanction levied is maximal.[2] Here, courts are presumed to be constrained by existing tort law, which operates to fully compensate victims for harm sustained. Courts are permitted to deviate from this principle only to the extent that all legal liability may be denied where the firm has complied with a particular regulatory standard.

[1] Cite to false moral hazard models.

[2] Cite to maximal punishment literature.

[*Results of the Paper*]

The strategy of the paper is as follows. Section II presents the basic model. Equilibrium results are obtained in Section III and discussed in Section IV. Two extensions of the basic model are presented in Section V. Section VI briefly concludes.

2 The Basic Model

For a given level of precaution, x, an accident occurs with probability, $\alpha(x)$, where α is downward-sloping and convex over the relevant region. In addition, $0 < \alpha(x) < 1$. If an accident occurs, then the harm incurred by the victim is $H > 0$. The magnitude of this harm is equal to

$$H = \theta - x$$

where $\theta > 0$ is private information held by the firm. It is common knowledge that θ is distributed according to the cumulative distribution function, $F(\theta)$. Assume $\theta > x$ for all relevant x, and hence, $H > 0$.

In exerting positive effort, $x > 0$, the firm, hence, decreases both the probability, as well as the magnitude of harm, this more realistic than modelling only the probability, α, as a function of effort, as is commonly assumed in the literature. The cost of such precautionary effort to the firm is given by the function, $\psi(x)$, where ψ is upward-sloping and convex over the relevant region.

The risky activity has a value to consumers equal to V. If the risk, for example, is the possibility of a manufacturing defect in a product, then V corresponds to the benefit received by the consumer in purchasing that product. For simplicity, assume that, for all relevant x, $V > \max[\psi(x), H]$, which implies that it is socially optimal for the firm to engage in the risky activity.

The relevant social welfare criterion is given as the minimization of a weighted sum of the cost of care, $\psi(x)$, and expected harm, $\alpha(x)(\theta - x)$. Specifically,

$$\min_{x} \quad S(x) = \beta\alpha(x)(\theta - x) + (1 - \beta)\psi(x)$$

where $0 < \beta < 1$. Since $\theta > x$, the social welfare criterion is convex with respect to x, and the first-best level of precaution is, therefore, given by the first-order condition:[3]

$$\beta[\alpha'(x^{FB})(\theta - x^{FB}) - \alpha(x^{FB})] = -(1 - \beta)\psi'(x^{FB})$$

which, of course, implies that the weighted expected marginal benefits, $\beta[\alpha'(x^{FB})(\theta - x^{FB}) - \alpha(x^{FB})]$, equals the weighted marginal cost of care, $-(1 - \beta)\psi'(x^{FB})$.[4]

[3] Differentiating S twice with respect to x,

$$S''(x) = \beta\alpha''(x)(\theta - x) - 2\beta\alpha'(x) + (1 - \beta)\psi''(x)$$

Since $\alpha'' > 0$, $\alpha' < 0$, $\psi'' > 0$, and $\theta > x$, it follows that $S''(x) > 0$.

[4] While there is no difficulty in allowing zero or negative efforts, for expositional simplicity, it is assumed that efforts remain strictly positive over the relevant range of equilibrium efforts.

Furthermore, observe that the first-best level of precaution, $x^{FB}(\theta)$, is a function of the harm parameter, θ, and is increasing in θ.[5]

2.1 Legal Regime

The firm is subject to ex post legal liability and, moreover, that liability is assumed to be strict, where strict liability means that a firm must fully compensate the victim for harm incurred in the event of an accident, irrespective of the level of precaution undertaken by the firm. The legal regime, however, is assumed to be *imperfect* to the extent that an injurer escapes suit with probability, δ, where $0 < \delta < 1$.[6] That is, if the firm's risky activity causes an accident, then the firm is sued with probability δ, rather than with probability 1, as would be the case were the legal regime perfect. Moreover, this probability, δ, is assumed to be the same for every firm.

Where strict liability is the sole means of controlling external risk, the injurer chooses x to minimize its expected legal liabilities

$$\delta\alpha(x)(\theta - x) + \psi(x)$$

The first-order condition is

$$\delta[\alpha'(x_S)(\theta - x_S) - \alpha(x_S)] = -\psi'(x_S)$$

which, of course, implies that the marginal expected benefits of decreased liability, $\delta[\alpha'(x)H - \alpha(x)]$, equals the marginal cost of care, $-\psi'(x)$. This level of precaution, $x_S(\theta)$, can be expressed as function of the parameter θ, and it is easy to show that it is also increasing in θ.[7]

2.2 Regulatory Framework

The firm is also subject to ex ante regulation, where the regulator is endowed with the following set of regulatory instruments.

First, the regulator is able to set a regulatory standard, s. If the firm complies with this standard, then the regulator reduces its expected legal liability

[5] Since $\alpha' < 0$; $\alpha'' > 0$; and $\psi'' > 0$, it follows that $\frac{dx}{d\theta} = \frac{\alpha'(\cdot)}{\beta[\alpha'(\cdot) - \alpha''(\cdot)(\theta - x)] - (1-\beta)\psi''(\cdot)} > 0$.

[6] Note of course that if the legal regime were operating perfectly and firm are not judgment-proof, then the regulator can overcome the moral hazard problem by creating sufficiently large wedge between the payoffs in the event of an accident and of no accident.

This result does not obtain here because not everybody brings suits and it is assumed that regulators cannot simply replicate this system. We abstract from the further problem of judgment proof but note it could be a problem.

[7] Differentiating with respect to θ yields

$$\frac{dx_S}{d\theta} = \frac{-\delta\alpha'(\cdot)}{\delta[\alpha''(\cdot)H - \alpha'(\cdot)] + \psi''(\cdot)} > 0$$

since $\alpha'(x) < 0$ and $\alpha''(x) > 0$.

up to an amount $\delta\alpha(s)H$. In particular, assume that the regulator relieves the firm of strict liability for harm H with probability $\delta\alpha(s)$. Furthermore, if the firm's expected legal liability is less than $\delta\alpha(s)H$, then its liability is reduced only up to that amount, where this expectation can be interpreted as the regulator playing a long-run strategy in repeated interactions with firms in the regulated industry.

In equilibrium, agreeing to reduce expected legal liability up to an amount $\delta\alpha(s)H$, ex ante, will be equivalent to holding the firm not liable, ex post, in all suits filed against the firm. That the regulator must limit its grant of no-liability in this fashion provides support for the claim that a firm's compliance with a regulated standard in a particular court case should not always relieve the firm of legal liability.[8] That is, in order to implement the following regulatory contract, courts (on the advice of the regulator) must be able to hold the firm strictly liable where its actual expected legal liabiliy exceeds $\delta\alpha(s^*)H$.

Second, in addition to reducing its legal liability, in order to induce the firm to accept the regulatory standard, the regulator may also compensate the firm with a net transfer $t \geq 0$. Assume for the sake of generality that the government is prohibited by law from directly paying money to the firm, and thus, interpret the transfer, t, as a tax deduction granted to the firm if the regulatory standard is met. The non-negativity constraint implies that no tax penalties are levied. The regulator cannot punish the firm. Only the court can impose sanctions.[9] Hence, unlike Hiriart et al. (2004), transfers do not depend on whether or not there occurs an accident. There is a single transfer made to the firm before any accident should occur.

Third, the regulator can increase the probability of suit, δ, that a *particular* firm faces, but this is costly.[10] As an example, a regulatory statute of limitations may govern the personal injury action based on strict liability. Increasing this statute of limitations will, on average, increase the number of suits filed, and thus, the number of victims rightly compensated for their injuries, but the regulator will also incur costs in extending the statutory period; for instance, increased pressure on the State by industry lobbying groups to cut the regulatory agency's operating budget.[11]

Formally, let $0 < \delta_B < 1$ denote the baseline probability of suit for all firms in the event of an accident. The cost to the regulator of pegging the probability of suit at this level is, of course, therefore, equal to zero; that is, $c(\delta_B) = 0$. Increasing the probability of suit from this baseline, however, results in positive marginal costs to the regulator, $c'(\cdot) > 0$, which are continuously increasing on $[\delta_B, 1]$; that is, $c''(\cdot) > 0$ for $\delta \in [\delta_B, 1]$. Moreover, the following Inada

[8] Insert cite to a paper that makes this claim.

[9] We constrast this with the case of audit.

[10] Cite to Hiriat (2006) where control agency is concerned about a audit. Different though for the following reasons.

[11] This is exogenous in Shavell and Hiriart et al as well as costless 2004. In Hiriart, it is now an instrument possessed by the control agency and it is costly. However, the regulator audits care, the judge liability. We model legal liability here as a substitute to the ex ante audit conducted in that paper.

conditions are assumed to hold: $c'(\delta_B) = 0$ and $c'(1) = \infty$.[12]

Let C denote the firm's cost function:

$$C = \psi(x) - t$$

In its relationship with the regulator, the firm's costs must be at least as low as what obtains outside the relationship. The firm is presumed outside the relationship if it does not comply with the regulatory standard, in which case it is held strictly liable for all accidents caused by its risky activity. Recalling that $x_S(\theta)$ denotes the level of precaution taken by the firm where strict liability is the sole means of controlling risk, the firm's individual rationality (IR) constraint is, accordingly, given by

$$C \leq \delta\alpha(x_S(\theta))(\theta - x_S(\theta)) + \psi(x_S(\theta))$$

Assuming lump-sum taxes are not available, and thus, taxation to be distortionary, the regulator faces a shadow cost of public funds, $\lambda \geq 0$; in other words, transferring \$1 to firms in the form of tax benefits inflicts disutility $\$(1 + \lambda)$ on taxpayers/potential victims. The regulator's *ex post* social welfare criterion is the minimization of the following expression

$$\beta_1\alpha(x)(\theta - x) + \beta_2\psi(x) + \beta_3\lambda t + (1 - \beta_1 - \beta_2 - \beta_3)c(\delta)$$

where $\beta_i > 0$ for $i = 1, 2, 3$ and $0 < \beta_1 + \beta_2 + \beta_3 < 1$.

Observe that the regulator dislikes granting the firm a tax deduction t. The regulator, however, is indifferent between whether consumers or firms bear the risk of accident; that is, the regulator seeks to minimize the total cost of accident including the cost of precaution, but it does not care how the legal system distributes these costs between firms and consumers. Also, note that the probability of suit, δ, appears only as a direct cost in the social welfare criterion. The regulator derives no *direct* benefit from a legal regime that is any more or less imperfect.

3 Equilibrium

This section derives the equilibrium outcomes under complete and incomplete information, respectively.

3.1 Complete Information

Assume that the regulator is a Stackelberg leader and makes a take-it-or-leave-it offer to the firm. Under complete information, the regulator, therefore, solves

$$\min_{\{t,s,\delta\}} \beta_1\alpha(s)(\theta - s) + \beta_2\psi(s) + \beta_3\lambda t + (1 - \beta_1 - \beta_2 - \beta_3)c(\delta)$$

[12] The regulator is *not* endowed with an audit technology, τ, that can detect the agent's level of precaution and allows for punishment when the firm takes a level of precaution which differs from the regulatory standard. In a later section, the equilibrium outcome under the preceding set of regulatory instruments will be compared to that which obtains when the regulator can, indeed, engage in costly state verification.

subject to

$$\psi(s) - t \leq \psi(x_S(\theta)) + \delta\alpha(x_S(\theta))(\theta - x_S(\theta))$$

and $t \geq 0$.

To interpret, if the firm does not comply with the regulatory standard, then it is presumed to be outside of the relationship and, therefore, strictly liable for any accidents that it causes. The harm caused by the firm is assumed never to exceed its assets; that is, the regulatory contract need not satisfy a limited liability constraint: $t \geq -y$. Ex post legal liability must be a real threat that the regulator can relieve if only if the firm complies with a regulatory standard.

To solve this program, consider the first-order conditions

$$\beta_1[\alpha'(s^*)(\theta - s) - \alpha(s)] = -\beta_2\psi'(s^*) - \mu_1\psi'(s^*)$$

$$(1 - \beta_1 - \beta_2 - \beta_3)c'(\delta^*) = \mu_1\alpha(x_S(\theta))(\theta - x_S(\theta))$$

$$\beta_3\lambda = \mu_1 + \mu_2$$

as well as the complementary slackness conditions

$$\mu_1[\psi(s^*) - t - [\psi(x_S(\theta)) + \delta^*\alpha(x_S(\theta))(\theta - x_S(\theta))] = 0 \quad \text{and} \quad \mu_2 t = 0$$

There are two cases to consider.

First, suppose that the IR constraint is *not* binding. It follows from the first complementary slackness condition that $\mu_1 = 0$. The equality, $\beta_3\lambda = \mu_1 + \mu_2$, implies $\beta_3\lambda = \mu_2 > 0$, and, from the second slackness condition, $t^* = 0$. The optimal s^* and δ^* are, therefore, given by

$$\beta_1[\alpha'(s^*)(\theta - s^*) - \alpha(s^*)] = -\beta_2\psi'(s^*)$$

$$(1 - \beta_1 - \beta_2 - \beta_3)c'(\delta^*) = 0$$

To interpret briefly, there is no distortion with respect to the first-best level of precaution; that is, $s^* = x^{FB}(\theta)$. In addition, recalling $c'(\delta_B) = 0$, the regulator does not incur a cost to increase the probability of suit above the pre-existing baseline; that is, $\delta^* = \delta_B$.

Second, suppose now that the IR constraint is binding. The optimal transfer, t^*, hence, is determined by

$$t^* = \psi(s^*) - [\psi(x_S(\theta)) + \delta^*\alpha(x_S(\theta))\theta] > 0$$

which implies $\mu_2 = 0$, and thus, that $\beta_3\lambda = \mu_1 > 0$.[13] The optimal s^* and δ^* are, hence, given by

$$\beta_1[\alpha'(s^*)(\theta - s^*) - \alpha(s^*)] + \beta_2\psi'(s^*) = -\beta_3\lambda\psi'(s^*)$$

[13] For ease of exposition, we ignore the unlikely case where

$$\psi(s^*) = \psi(x_l(H)) + \delta^*\alpha(x_l(H))H$$

and thus

$$t^* = 0$$

$$(1 - \beta_1 - \beta_2 - \beta_3)c'(\delta^*) = \beta_3 \lambda \alpha(x_S(\theta))(\theta - x_S(\theta))$$

Since $S(\cdot)$ is convex, $S'(\cdot) < 0$ implies that there is a downward distortion with respect to the first-best level of precaution; that is, $s^* = s^*_{IR} < x^{FB}(\theta)$. The existing legal regime is sufficiently imperfect that in order to induce the firm to accept the regulatory standard, the regulator must make a positive transfer to the firm, t, in addition to the grant of no-liability. Such transfers costly, the regulator, thus, sets the marginal social benefit of decreasing the transfer equal to the marginal social cost of decreasing the regulatory standard of care, s^*, away from the optimum, $x^{FB}(\theta)$.

Moreover, $(1 - \beta_1 - \beta_2 - \beta_3)c'(\delta^*) > 0$ implies $\delta^* > \delta_B$; that is, the regulator, now, incurs a positive cost to increase the probability of suit above the pre-existing baseline. In particular, the regulator sets of the marginal social cost of increasing the probability of suit equal to the marginal social benefit of decreasing the transfer needed to satisfy individual rationality by the marginal amount, $\alpha(x_S(H))H$.

3.2 Incomplete Information

Suppose, now, that regulation is subject to both adverse selection and moral hazard. Specifically, assume that the regulator cannot observe whether or not the firm has complied with the regulatory standard, s. In other words, the level of precautionary effort undertaken is private information held by the firm. Similarly, suppose that the regulator cannot directly observe θ, but knows that θ belongs to the two-point support $\{\underline{\theta}, \overline{\theta}\}$, with $\Delta\theta = \overline{\theta} - \underline{\theta} > 0$. The regulator has a prior distribution on the values of θ characterized by $v = Pr(\theta = \underline{\theta})$ and $1 - v = Pr(\theta = \overline{\theta})$.

The regulator, however, can observe the actual harm, H, realized in the event of an accident. If the regulator is able to achieve separation with respect to θ, then, in effect, effort becomes observable as well, allowing the regulator to implement a mechanism resembling the case of observable precautionary effort in Hiriart et al. (2004), albeit, unlike in that case, not one that implements the first-best. Moreover, note that the judge can neither observe type ex post, nor can it conduct its own independent audit. Therefore, unlike Hiriart et al. (2006), the adverse selection problem is solved entirely by the regulator.
The court merely imposes strict liability, which, given $\delta < 1$, is assumed insufficient to solve either the moral hazard or adverse selection problem.

Specifically, a regulatory contract between the firm and the regulator is based on the ex post jointly observable variables: t, δ, and H.[14] Excluding stochastic contracts without loss of generality, a contract based on these observable variables specifies a transfer-probability-harm triple for each type of firm, namely, $\{\underline{t}, \underline{\delta}, \underline{H}\}$ for type $\underline{\theta}$ and $\{\overline{t}, \overline{\delta}, \overline{H}\}$ for type $\overline{\theta}$. For notational simplicity, set $\overline{t} \equiv t(\overline{\theta})$, $\overline{\delta} \equiv \delta(\overline{\theta})$, and $\overline{H} \equiv \overline{H}(\overline{\theta})$, and, similarly, for type $\underline{\theta}$.

From above, individual rationality for each type firm follows immediately as

$$\psi(\underline{\theta} - \underline{H}) - \underline{t} \leq \psi(x_S(\underline{\theta})) + \underline{\delta}\alpha(x_S(\underline{\theta}))(\underline{\theta} - x_S(\underline{\theta}))$$

[14] Comment more on the fact that it is not really H, but $\delta\alpha(x)H$.

$$\psi(\overline{\theta} - \overline{H}) - \overline{t} \leq \psi(x_S(\overline{\theta})) + \overline{\delta}\alpha(x_S(\overline{\theta}))(\overline{\theta} - x_S(\overline{\theta}))$$

Note that $\underline{\delta}$ and $\overline{\delta}$, rather than δ, appear in the two IR constraints, respectively. These suits are assumed to be brought, ex post, with probabilities set by the regulator, ex ante. Moreover, the regulator is not required to compensate the firm for increasing the ex post efficiency of the legal regime; that is, the regulator need not pay $(\delta' - \delta)\alpha(x_S(\theta))(\theta - x_S(\theta))$ to the firm, where $\delta' > \delta$.

Incentive compatibility (IC) in this particular information environment means that the contract designed for type $\overline{\theta}$ is preferred by type $\overline{\theta}$ above all others in the menu of transfer-probability-harm triples. And, similarly, the contract designed for type $\underline{\theta}$ is preferred by type $\underline{\theta}$ above all others in the same menu. That is,

$$\psi(\underline{\theta} - \underline{H}) - \underline{t} \leq \psi(\underline{\theta} - \overline{H}) - \overline{t} + \overline{\delta}[\alpha(\underline{\theta} - \overline{H}) - \alpha(\overline{\theta} - \overline{H})]\overline{H}$$
$$\psi(\overline{\theta} - \overline{H}) - \overline{t} \leq \psi(\overline{\theta} - \underline{H}) - \underline{t}$$

To amplify, recall that the regulator cannot reduce a firm's expected legal liability by an amount that exceeds its actual expected legal liability. Since $\underline{\delta}\alpha(\overline{\theta} - \underline{H})\underline{H} < \underline{\delta}\alpha(\underline{\theta} - \underline{H})\underline{H}$, type $\overline{\theta}$'s liability is reduced only up to the former amount if it misreports type in choosing the contract designed for type $\underline{\theta}$. If the type $\underline{\theta}$ firm, however, misreports type, since its actual expected legal liability, $\overline{\delta}\alpha(\underline{\theta} - \overline{H})\overline{H}$, exceeds the reduction granted by the regulator, $\overline{\delta}\alpha(\overline{\theta} - \overline{H})\overline{H}$, it remains liable for the difference.

Observe that the probability of suit, $\overline{\delta}$, appears only in the IC constraint for the type $\underline{\theta}$ firm, where the more likely it is that a type $\overline{\theta}$ firm is sued, the greater the expected liability incurred in misreporting type, and thus, the more attractive the contract designed for the type $\overline{\theta}$ firm. By contrast, because type $\overline{\theta}$ incurs no legal liability under either contract, the probability of suit, $\underline{\delta}$, has no impact on its IC constraint.

Rewrite the IC constraint for type $\underline{\theta}$ as follows:

$$\psi(\underline{\theta} - \underline{H}) - \underline{t} \leq \psi(\underline{\theta} - \overline{H}) - \overline{t} + \overline{\delta}\Phi(\overline{H})$$

where

$$\Phi(\overline{H}) = [\alpha(\underline{\theta} - \overline{H}) - \alpha(\overline{\theta} - \overline{H})]\overline{H} > 0$$

and $\Phi'(\overline{H}) > 0$.[15]

Make the following assumption with respect to the primitives of the model, $\alpha(\cdot)$ and $\psi(\cdot)$, respectively: for all relevant $\overline{H}$, suppose that

$$\int_{\underline{\theta}}^{\overline{\theta}} \{\psi'(\theta - \overline{H}) + \overline{\delta}\alpha'(\theta - \overline{H})\overline{H}\} d\theta$$

[15] Differentiating $\Phi(H)$ with respect to H,

$$\Phi'(\overline{H}) = [\alpha(\underline{\theta} - \overline{H}) - \alpha(\overline{\theta} - \overline{H})] + [\alpha'(\overline{\theta} - \overline{H}) - \alpha'(\underline{\theta} - \overline{H})]\overline{H}$$

the first term is positive since $\alpha' < 0$, the second because $\alpha'' > 0$.

$$\geq \psi(x_S(\overline{\theta})) - \psi(x_S(\underline{\theta})) + \overline{\delta}\alpha(x_S(\overline{\theta}))(\overline{\theta} - x_S(\overline{\theta})) - \underline{\delta}\alpha(x_S(\underline{\theta}))(\underline{\theta} - x_S(\underline{\theta}))$$

To interpret, at all relevant $\overline{H}$, the function, $\alpha(\cdot)\overline{H}$, must be flat compared to $\psi(\cdot)$. That is, the marginal benefit of distorting $\overline{H}$ upwards must not be so large as to render irrelevant the marginal benefit of lowering the effort level requested from the inefficient type. In other words, expected legal liability is assumed *not* to solve the incentive compatibility problem perfectly.

Observe that this assumption, coupled with incentive compatibility for the efficient type, $\underline{\theta}$, and individual rationality for the inefficient type, $\overline{\theta}$, imply individual rationality for the efficient type (summarized in the following lemma).

Lemma 1 *The IC constraint for the type $\underline{\theta}$ firm can be ignored.*

Proof. To show that the IR constraint for the type $\underline{\theta}$ firm can be ignored, apply successively the IC constraint for type $\underline{\theta}$, the IR constraint for type $\overline{\theta}$, and the above assumption:

$$\psi(\underline{\theta} - \underline{H}) - \underline{t} \leq \psi(\underline{\theta} - \overline{H}) - \overline{t} + \overline{\delta}\Phi(\overline{H})$$

$$\leq [\psi(\underline{\theta} - \overline{H}) - \psi(\overline{\theta} - \overline{H})] + [\psi(x_S(\overline{\theta})) + \overline{\delta}\alpha(x_S(\overline{\theta}))(\overline{\theta} - x_S(\overline{\theta}))] + \overline{\delta}\Phi(\overline{H})$$

$$\leq \psi(x_S(\underline{\theta})) + \underline{\delta}\alpha(x_S(\underline{\theta}))(\underline{\theta} - x_S(\underline{\theta}))$$

■

In solving the regulator's maximization program, momentarily neglect the IC constraint for the type $\overline{\theta}$ firm, where it will later be checked that the solution satisfies this constraint under the following additional assumption regarding the first-best complete information solution for the two types of firms:

$$H^*(\overline{\theta}) = \overline{\theta} - s^*(\overline{\theta}) \geq \underline{\theta} - s^*_{IR}(\underline{\theta}) = H^*_{IR}(\underline{\theta})$$

where $s^*(\theta)$ denotes the optimal regulatory standard for type $\overline{\theta}$ under complete information when the IR constrant is *not* binding and, similarly, $s^*_{IR}(\overline{\theta})$ denotes the optimal regulatory standard under complete information when the IR constrant is binding.[16] Since $s^*(\overline{\theta}) > s^*_{IR}(\underline{\theta})$, note that, for certain values of the parameters $\underline{\theta}$ and $\overline{\theta}$, it is possible that the inequality $H^*(\overline{\theta}) < H^*_{IR}(\underline{\theta})$ might hold true, in which case, the IC constraint for type $\overline{\theta}$, rather than the IC constraint for type $\underline{\theta}$, will be that which binds at the optimum. Because the focus of the present analysis is on the impact of ex post strict liability on ex ante regulation and legal liabilty does not appear in the IC constraint for the type $\overline{\theta}$ firm, the preceding assumption is made, therefore, to suppress a case beyond the scope of this analysis.

To show that the IC constraint for type $\underline{\theta}$ is binding, proceed by contradiction. In particular, suppose that

$$\psi(\underline{\theta}-\underline{H})-\underline{t} < \overline{\delta}\Phi(\overline{H})-[\psi(\overline{\theta}-\overline{H})-\psi(\underline{\theta}-\overline{H})]+[\psi(x_S(\overline{\theta}))+\overline{\delta}\alpha(x_S(\overline{\theta}))(\overline{\theta}-x_S(\overline{\theta}))]$$

[16] This accords with the law and economics literature on tort in which effort is more more commonly modelled as determining the probability of harm, and not the magnitude of harm as well.

$$\leq [\psi(x_S(\underline{\theta})) + \underline{\delta}\alpha(x_S(\underline{\theta}))(\underline{\theta} - x_S(\underline{\theta}))]$$

which implies $\underline{t}$ can be decreased without violating IR or IC for type $\underline{\theta}$. Since such tranfers are costly to the regulator, this increases payoffs, and, therefore, the original mechanism cannot be optimal.

Substituting, thus, for $\psi(\underline{\theta} - \underline{H}) - \underline{t}$, the Lagragian for the regulator's optimization program can be written as

$$\min_{\{\underline{H},\overline{H},\underline{\delta},\overline{\delta}\}} v\{\beta_1\alpha(\underline{\theta}-\underline{H})\underline{H}+(\beta_2+\beta_3\lambda)\psi(\underline{\theta}-\underline{H})-\beta_3\lambda\psi(\underline{\theta}-\overline{H})-\beta_3\lambda\overline{\delta}\Phi(\overline{H})+(1-\beta_1-\beta_2-\beta_3)c(\underline{\delta})\}$$

$$+(1-v)\{\beta_1\alpha(\overline{\theta}-\overline{H})\overline{H} + \beta_2\psi(\overline{\theta}-\overline{H}) + (1-\beta_1-\beta_2-\beta_3)c(\overline{\delta})\}$$

$$+\mu_1[\psi(\overline{\theta}-\overline{H}) - \psi(x_S(\overline{\theta})) - \overline{\delta}\alpha(x_S(\overline{\theta}))(\overline{\theta} - x_S(\overline{\theta}))]$$

where μ_1 is the Lagragian multiplier corresponding to the IR constraint for type $\overline{\theta}$.

The first-order conditions with respect to $\underline{H}$ and $\underline{\delta}$ are, respectively,

$$-[\beta_1\alpha'(\underline{\theta}-\underline{H})\underline{H} - \beta_1\alpha(\underline{\theta}-\underline{H}) + \beta_2\psi'(\underline{\theta}-\underline{H})] = \beta_3\lambda\psi'(\underline{\theta}-\underline{H})$$

$$(1-\beta_1-\beta_2-\beta_3)c'(\underline{\delta}) = 0$$

The first-order condition with respect to $\underline{H}$ implies $\underline{s}^* = s^*_{IR}(\underline{\theta})$. The first-order condition with respect to $\underline{\delta}$ implies $\underline{\delta}^* = \delta_B$, and thus, $c(\underline{\delta}^*) = 0$.

Similarly, the first-order conditions with respect to $\overline{H}$, $\overline{\delta}$, and $\overline{t}$ are, respectively,

$$-[\beta_1\alpha'(\overline{\theta}-\overline{H})\overline{H}-\beta_1\alpha(\overline{\theta}-\overline{H})+\beta_2\psi'(\overline{\theta}-\overline{H})] = \frac{1}{1-v}\{\mu_1\psi'(\overline{\theta}-\overline{H})+\beta_3\lambda v(\overline{\delta}\Phi'(\overline{H})-\psi'(\underline{\theta}-\overline{H}))\}$$

$$(1-\beta_1-\beta_2-\beta_3)c'(\overline{\delta}) = \frac{1}{1-\nu}[\beta_3\lambda\nu\Phi(\overline{H}) + \mu_1\alpha(x_S(\overline{\theta}))(\overline{\theta} - x_S(\overline{\theta}))]$$

$$\beta_3\lambda = \mu_1 + \mu_2$$

There are two cases to consider.

First, if the IR constraint is binding, then $\overline{t}^*$ is given by

$$\overline{t}^* = \psi(\overline{\theta} - \overline{H}^*) - [\psi(x_S(\overline{\theta})) + \overline{\delta}\alpha(x_S(\overline{\theta}))(\overline{\theta} - x_S(\overline{\theta}))] > 0$$

and $\mu_2 = 0$, which implies $\mu_1 = \beta_3\lambda$.[17] The first-order condition with respect to $\overline{H}$ then implies $\overline{s}^* \leq s^*_{IR}(\overline{\theta})$, if $\psi'(\underline{\theta} - \overline{H}) \leq \overline{\delta}\Phi'(\overline{H})$, and $\overline{s}^* > s^*_{IR}(\overline{\theta})$, if $\psi'(\underline{\theta} - \overline{H}) > \overline{\delta}\Phi'(\overline{H})$. Since $\psi'(\overline{\theta} - \overline{H}) > v\psi'(\underline{\theta} - \overline{H})$, it follows that $S'(\overline{\theta}) > 0$, and thus, $\overline{s}^* < s^*(\overline{\theta})$, even where $\psi'(\underline{\theta} - \overline{H}) > \overline{\delta}\Phi'(\overline{H})$.

[17] For ease of exposition, the case where

$$\psi(s^*) = \psi(x_l(H)) + \delta^*\alpha(x_l(H))H$$

and thus

$$t^* = 0$$

is ignored.

Second, if the IR constraint is *not* binding, then the slackness condition, $\mu_1[\psi(\overline{\theta} - \overline{H}) - \overline{t} \leq \psi(x_S(\overline{\theta})) + \overline{\delta}\alpha(x_S(\overline{\theta}))(\overline{\theta} - x_S(\overline{\theta}))]$, implies $\mu_1 = 0$. Since $\mu_2 = \beta_3\lambda > 0$, $\mu_2\overline{t} = 0$ implies $\overline{t}^* = 0$. The first-order condition with respect to $\overline{H}$ then implies $\overline{s}^* \leq s^*(\overline{\theta})$, if $\psi'(\underline{\theta} - \overline{H}) \leq \overline{\delta}\Phi'(\overline{H})$. On the other hand, if $\psi'(\underline{\theta} - \overline{H}) > \overline{\delta}\Phi'(\overline{H})$, then $\overline{s}^* > s^*(\overline{\theta})$, and, in this case, it is, thus, possible that $\underline{H}^* > \overline{H}^*$. Recall, however, that

$$\underline{t}^* = \psi(\underline{\theta} - \underline{H}^*) - \psi(\underline{\theta} - \overline{H}^*) - \overline{\delta}\Phi(\overline{H}^*) \geq 0$$

which implies $\underline{H}^* \leq \overline{H}^*$. Hence, if the first-order conditions above imply $\underline{H}^* > \overline{H}^*$, then this cannot be an optimal solution, because the non-negativity constraint $\underline{t} \geq 0$ is not satisfied. To support this optimal solution, tax penalties are required, but such penalties are not allowed in equilibrium.[18]

Moreover, the inequality, $\underline{H}^* \leq \overline{H}^*$, implies that the neglected IC constraint for type $\overline{\theta}$ is, indeed, satisfied at the optimum. To see this, observe that this constraint can be written as

$$-\int_{\underline{H}}^{\overline{H}}\int_{\underline{\theta}}^{\overline{\theta}} \psi''(\theta - H)d\theta dH \leq \overline{\delta}\Phi(\overline{H})$$

which is clearly satisfied where $\underline{H}^* \leq \overline{H}^*$, since $\psi'' > 0$, $\overline{\theta} > \underline{\theta}$, and $\overline{\delta}\Phi(\overline{H}) > 0$.

In the case where $\overline{t}^* > 0$ or $\psi'(\underline{\theta} - \overline{H}) \leq \overline{\delta}\Phi'(\overline{H})$, it is easy to show that the inequality, $\underline{H}^* \leq \overline{H}^*$, is satisfied at the optimal regulatory solution, $\{\underline{s}^*, \overline{s}^*\}$. Recall, by assumption,

$$H^*(\overline{\theta}) = \overline{\theta} - s^*(\overline{\theta}) \geq \underline{\theta} - s^*_{IR}(\underline{\theta}) = H^*_{IR}(\underline{\theta})$$

Because $\underline{s}^* = s^*_{IR}(\underline{\theta})$ and $\overline{s}^* \leq s^*(\overline{\theta})$, it follows that

$$\overline{H}^* = \overline{\theta} - \overline{s}^* \geq \underline{\theta} - \underline{s}^* = \underline{H}^*$$

which implies $\overline{H}^* \geq \underline{H}^*$, as desired.

The case where $\overline{t}^* = 0$ and $\psi'(\underline{\theta} - \overline{H}) > \overline{\delta}\Phi'(\overline{H})$, however, does not follow as straightforwardly to the extent that it may require an additional assumption; specifically, $\overline{\theta} - \overline{s}^+ \geq \underline{\theta} - s^*_{IR}(\underline{\theta})$, where $\overline{s}^+$ denotes the optimal regulatory standard of care chosen such that $\overline{s}^+ > s^*(\overline{\theta})$.

Finally, since $\frac{\beta_3\lambda}{\nu}(1-\nu)\Phi(\overline{H}) > 0$, the inequalities $\overline{\delta}^* > \delta_B$ and $c(\overline{\delta}^*) > 0$ hold true, irrespective of whether or not the IR constraint is binding.

These results are summarized in the following proposition.

Proposition 2 *Under ex ante regulation, the optimal contract entails: Only the probability of suit for the inefficient type, $\overline{\delta}^*$, is increased such that*

$$(1 - \beta_1 - \beta_2 - \beta_3)c'(\overline{\delta}^*) = \frac{1}{1-\nu}[\beta_3\lambda\nu\Phi(\overline{H}^*) + \mu_1\alpha(x_S(\overline{\theta}))(\overline{\theta} - x_S(\overline{\theta}))]$$

[18] For expositional simplicity, assume that the $\overline{s}^*$ which obtains in this case, indeed, yields

$$\psi(\underline{\theta} - H^*_{IR}(\underline{\theta})) - \psi(\underline{\theta} - \overline{H}^*) - \overline{\delta}\Phi(\overline{H}^*) = \underline{t}^* \geq 0$$

Of course, this would need to be checked if there were explicit functional forms.

No output distortion with respect to the first-best outcome for the efficient type, assuming the IR constraint binds with complete information, $\underline{s}^* = s^*_{IR}(\underline{\theta})$ and a downward distortion for the less efficient type equal to

$$-[\beta_1\alpha'(\overline{\theta} - \overline{H}^*)\overline{H}^* - \beta_1\alpha(\overline{\theta} - \overline{H}^*) + \beta_2\psi'(\overline{\theta} - \overline{H}^*)]$$

$$= \frac{1}{1-v}\{\mu_1\psi'(\overline{\theta} - \overline{H}^*) + \beta_3\lambda v(\overline{\delta}\Phi'(\overline{H}^*) - \psi'(\underline{\theta} - \overline{H}^*))\}$$

The transfers to the type $\overline{\theta}$ and $\underline{\theta}$ firms, respectively, are given by

$$\underline{t}^* = \psi(\underline{\theta} - \underline{H}^*) - \psi(\underline{\theta} - \overline{H}^*) - \overline{\delta}\Phi(\overline{H}^*)$$

$$\overline{t}^* = 0 \quad or \quad \overline{t}^* = \psi(\overline{\theta} - \overline{H}^*) - [\psi(x_S(\overline{\theta})) + \overline{\delta}\alpha(x_S(\overline{\theta}))(\overline{\theta} - x_S(\overline{\theta}))]$$

depending on whether the IR constraint for the type $\overline{\theta}$ firm is binding. In the case where $\overline{t}^* = 0$ and $\psi'(\underline{\theta} - \overline{H}^*) > \overline{\delta}\Phi'(\overline{H}^*)$, the following must be verified

$$\overline{\theta} - \overline{s}^+ \geq \underline{\theta} - s^*_{IR}(\underline{\theta})$$

where $\overline{s}^+$ denotes the optimal regulatory standard of care chosen such that $\overline{s}^+ > s^*(\overline{\theta})$.

4 Discussion of Results

In this section, the equilibrium outcome under incomplete information is described in greater detail and its welfare properties are examined.

4.1 Description of the Equilibrium

The equilibrium derived above is characterized by a mix of the regulatory instruments available. Specifically, with respect to type $\underline{\theta}$, the regulator makes a positive transfer to the firm in order to induce it to accept the contract designed for it. This transfer costly, the regulator sets the marginal social benefit of decreasing the transfer, $\beta_3\lambda\psi'(\cdot)$, equal to the marginal social cost of decreasing the standard away from the first-best level, $-[\beta_1\alpha'(\cdot)\underline{H} - \beta\alpha(\underline{\theta} - \underline{H}) + \beta_2\psi'(\cdot)]$, with $\underline{s}^* = s^*_{IR}(\underline{\theta})$ because decreasing the standard yields a marginal decrease in the transfer equal to that which obtains when the regulator decreases the standard to satisfy individual rationality.

The regulator, however, does not incur a cost to increase the probability of suit. Because the IR constraint is not binding, there is no benefit to the regulator in making it more costly for the type $\underline{\theta}$ firm to reject the regulatory contract. Similarly, because $\underline{\delta}$ does not appear in the IC constraint, increasing this probability does not increase the set of incentive compatible contracts. Under ex ante regulation, therefore, the efficiency of the legal regime with respect to type $\underline{\theta}$ will be increased by the regulator only if incentive compatibility for the type $\underline{\theta}$ firm can be ignored.

With respect to type $\overline{\theta}$, the regulator does not make a transfer payment but, rather, distorts its level of precaution, $\overline{s}^*$, downwards from the optimal first-best level. In misreporting type, the type $\underline{\theta}$ firm enjoys lower safety costs, $\psi(\underline{\theta}-\overline{H})$. It is, now, however, also exposed to positive expected legal liability, $\overline{\delta}\Phi(\overline{H})$, where this liability, thus, acts as a punishment to deter type $\underline{\theta}$ from lying. The larger the expected liability, the larger the punishment, and thus, the lower the reward (the transfer payment) needed to induce type $\underline{\theta}$ to choose the contract designed for it.

Specifically in decreasing the standard, the regulator sets the marginal social cost of decreasing the standard, $-[\beta_1[\alpha'(\overline{\theta}-\overline{H})\overline{H}-\alpha(\overline{\theta}-\overline{H})]+\beta_2\psi'(\overline{\theta}-\overline{H})]$, equal to the net marginal social benefit of decreasing the transfer payment, $\frac{1}{1-v}\{v\beta_3\lambda[\overline{\delta}\Phi'(\overline{H})-\psi'(\underline{\theta}-\overline{H})]+\mu_1\psi'(\overline{\theta}-\overline{H})\}$, where the first term represents the marginal benefit of increased punishment, the second term, the marginal cost of requiring less precautionary effort, and the third term, the additional marginal benefit of decreasing the transfer payment required to satisfy individual rationality, if that constraint is, indeed, binding. The sum of these effects is equal to the net marginal social benefit, which is positive since $\psi'(\overline{\theta}-\overline{H}) > v\psi'(\underline{\theta}-\overline{H})$.

Moreover, the regulator incurs a cost to increase the probability of suit, $\overline{\delta}$. Increasing $\overline{\delta}$ increases the legal liability to which the type $\underline{\theta}$ firm is exposed if it misreports type, thus increasing its incentive not to do so, which implies that the regulator need not pay as large a socially costly transfer to the firm in order to induce it to accepts the contract designed for it. In particular, the regulator sets the marginal cost of increasing this probability, $(1-\beta_1-\beta_2-\beta_3)c'(\overline{\delta}^*)$, equal to the marginal social benefit of decreasing the transfer required to satisfy the IC constraint, $\frac{v}{1-\nu}\beta_3\lambda\nu\Phi(\overline{H})$, as well as the marginal benefit of decreasing the transfer required to satisfy the IR constraint, $\frac{\beta_3\lambda}{1-\nu}\alpha(x_S(\overline{\theta}))(\overline{\theta}-x_S(\overline{\theta}))$, provided that constraint is, indeed, binding.

It is, therefore, in this particular sense that ex post legal liability acts as a *substitute* for ex ante regulation, defined as conditioning a positive transfer on compliance with a specific standard of precautionary care set by the regulator. More formally, observe that the first-order condition with respect $\overline{H}$ implicitly defines a continuous function, $\overline{\delta}(\overline{H})$.[19] To determine the sign of $\overline{\delta}^{*\prime}(\overline{H}^*)$, substitute this function into the first-order condition with respect to $\overline{\delta}$ and differentiate with respect to $\overline{H}$. That is,

$$\overline{\delta}^{*\prime}(\overline{H}^*) = \frac{\frac{\nu}{1-\nu}\beta_3\lambda\Phi'(\overline{H}^*)}{c''(\cdot)} > 0 \Longrightarrow \overline{\delta}^{*\prime}(\overline{s}^*) < 0$$

since $\Phi'(\overline{H}^*) > 0$ and $c''(\cdot) > 0$.

As the regulator distorts $\overline{H}^*$ upwards, or, equivalently, $\overline{s}^*$ downwards with respect to the first-best, this increases the marginal benefits associated with increasing the probability of suit from the baseline level, δ_B. That is, a lower s^*

[19] Given satisfaction of the appropriate second-order conditions.

implies a larger punishment if the firm misreports type, and, therefore, in satisfying incentive compatibility, the regulator is willing to incur larger marginal costs, c', to increase the frequency of this larger punishment.

4.2 Welfare Analysis

The welfare question here is motivated by the observation that the regulator might not want to lose the benefits of making the firm a residual claimant for the harm resulting from its risky activity by relieving it of strict liability in the event of an accident. In other words, the regulator faces a trade-off between solving the moral hazard problem by holding the firm strictly liable for harm caused by its risky activity and solving the adverse selection problem by relieving the firm of all such liability when it selects the regulatory contract designed for it. Provided certain conditions hold, the regulator may wish to simply increase the extent to which firms act as residual claimants, rather than eliminating this incentive mechanism altogether in conditioning no-liability on compliance with a particular regulatory standard of care.

Within the current framework, this is equivalent formally to positing that the regulator sets only δ, and not H or t. Let $\underline{x}_S(\delta_S)$ and $\overline{x}_S(\delta_S)$ denote the amount of care taken by the type $\underline{\theta}$ and type $\overline{\theta}$ firms, respectively, where the probability of suit for both types is equal to δ_S. It is straightforward to show that $x_S(\delta)$ is increasing in δ.[20]

The regulator's optimization program is, now, given as

$$\min_{\delta} \ v[\beta_1\alpha(\underline{x}_S(\delta))(\underline{\theta} - \underline{x}_S(\delta)) + \beta_2\psi(\underline{x}_S(\delta))]$$

$$+(1-v)[\beta_1\alpha(\overline{x}_S(\delta))(\overline{\theta} - \overline{x}_S(\delta)) + \beta_2\psi(\overline{x}_S(\delta))] + (1-\beta_1-\beta_2)c(\delta)$$

The first-order condition is

$$-(1-\beta_1-\beta_2)c'(\delta_S^*) = vS_\delta(\underline{\theta})\frac{d\underline{x}_S}{d\delta_S^*} + (1-v)S_\delta(\overline{\theta})\frac{d\overline{x}_S}{d\delta_S^*}$$

which implies that the magnitude of δ_S^* is a function of how responsive the firms are to probability, δ, in deciding what level of precautionary care to take; that is, $\frac{d\underline{x}_S}{d\delta_S^*}$ and $\frac{d\overline{x}_S}{d\delta_S^*}$, respectively.

Pure ex post strict liability as the sole means of controlling external risk is, thus, socially preferred to ex ante regulation if and only if

$$(1-v)[S(\overline{x}_S(\delta_S^*))-S(\overline{s}^*)]+c(\delta_S^*)-E[c(\delta_R^*)] < v[S(\underline{s}^*)-S(\underline{x}_S(\delta_S^*))]+\beta_3\lambda[\underline{t}^*+v\overline{t}^*]$$

where $E[c(\delta_R^*)] \equiv vc(\underline{\delta}^*) + (1-v)c(\overline{\delta}^*)$.

[20] Since $\alpha'(x) < 0$; $\alpha''(x) > 0$; and $\psi''(x) > 0$, it follows straightforwardly that

$$\frac{dx_S}{d\delta} = \frac{-\alpha'(x)H}{\psi''(x) + \delta\alpha''(x)H} > 0$$

.

Observe that ex ante regulation is always preferred to pure strict liability when no positive transfer payments are made to the firm. In this case, regulation yields the first-best outcome. Because $c'(1) = \infty$, and thus, $\delta_S^* < 1$, such an outcome is precluded under pure strict liability.

If the IR or IC constraint is binding, however, then pure ex post strict liability may be preferred to ex ante regulation. Observe that for any given x' such that $x' > \underline{x}_S(\delta_S^*)$, incentive compatibility is always satisfied under pure strict liability, since, by definition,

$$\psi(\underline{x}_S(\delta_S^*)) \leq \psi(x') + \overline{\delta}[\alpha(x')(\overline{\theta} - x') - \alpha(\underline{x}_S(\delta_S^*))(\underline{\theta} - \underline{x}_S(\delta_S^*))] \leq \psi(x') + \overline{\delta}\Phi'(H')$$

Similarly, the regulator obviously need not worry about individual rationality, because the firm does not enter into any contractual regulatory relationship with it. That these two constraints are, thus, satisfied for any given $\{\underline{x}_S(\delta_S^*), \overline{x}_S(\delta_S^*)\}$ is the benefit of pure strict liability under these assumptions.

By contrast, that the first-best outcome for the type $\underline{\theta}$ firm, $x^{FB}(\underline{\theta})$, no longer obtains, however, as well as the possibility that $\overline{x}_S(\delta_S^*) < \overline{s}^*$ and $c(\delta_S^*) > E[c(\overline{\delta})]$, represent the costs of pure strict liability as compared to ex ante regulation. If the social loss implied by these distortions is less than the cost to society of satisfying incentive compatibility and individual rationality, $\frac{v}{1-v}\beta_3\lambda[\underline{t}^* + v\overline{t}^*]$, then pure ex post strict liability will be the socially preferred means of controlling external risk.

Generally speaking, this is likely to be the case where the optimal regulatory solution implies large transfers to satisfy the IC and IR constraints and can be closely approximately, at relatively low cost, by increasing the probability of suit for all firms; that is, $\underline{t}^*$and $\overline{t}^*$ are large relative to $c(\delta_S^*)$ and precautionary effort undertaken by the two firms, $\{\underline{x}_S(\delta_S^*), \overline{x}_S(\delta_S^*)\}$, is approximately equal to the optimal regulatory solution, $\{\underline{s}^*, \overline{s}^*\}$.

5 Extensions

Extensions of the model developed above are considered in this section.

5.1 The Threat of Audit

The extension considered here is motivated by the observation that the regulator, rather than relying on ex post legal liability, might choose to eliminate legal liability altogether and use an audit technology that can detect the firm's nontruthful report and allows for some punishment when a false report is detected. Note that a no-liability legal regime is equivalent to $\delta_B = 0$. Let $x_N(\theta)$ denote the level of care undertaken in such a regime, where it is easy to show that $x_N(\theta) = 0$, and thus, by assumption, $\psi(x_N(\theta)) = 0$.

The audit technology is assumed to allow the regulator to verify the state of nature announced by the firm, at a cost, where the fact that the technology is costly prevents its systematic use by the regulator. Formally, assume that the regulator owns the audit technology and that the firm's true type can be observed with probability, p, if the regulator incurs a cost $\tau(p)$, where $\tau(0) = 0$, $\tau' > 0$, and $\tau'' > 0$. Moreover, assume that the following Inada conditions hold: $\tau'(0) = 0$ and $\tau'(1) = \infty$.

The possibility of an audit enlarges the set of incentive-feasible mechanisms, where the mechanism now includes, not only t and H, but also a probability of audit, $p(\theta)$, and a punishment, $P(\theta, \widetilde{\theta})$, if the firm's announcement $\widetilde{\theta}$ differs from its observed true type θ. Letting $\underline{P} = P(\underline{\theta}, \overline{\theta})$ and $\overline{P} = P(\overline{\theta}, \underline{\theta})$, incentive compatibility, now, amounts to

$$\psi(\underline{\theta} - \underline{H}) - \underline{t} \leq \psi(\underline{\theta} - \overline{H}) - \bar{t} + \overline{p}\underline{P}$$
$$\psi(\overline{\theta} - \overline{H}) - \bar{t} \leq \psi(\overline{\theta} - \underline{H}) - \underline{t} + \underline{p}\overline{P}$$

Suppose that punishments are *endogenously* determined as follows

$$\underline{P} \leq \bar{t} - \psi(\underline{\theta} - \overline{H})$$
$$\overline{P} \leq \underline{t} - \psi(\overline{\theta} - \underline{H})$$

That is, assume that the punishment cannot be greater than what the firm gains in misreporting type. The regulator is assumed to seize no additional assets in the event of a detected lie.

In equilibrium, in addition to these four constraints, individual rationality, of course, must also be satisfied, given here as

$$\psi(\underline{\theta} - \underline{H}) - \underline{t} \leq 0$$
$$\psi(\overline{\theta} - \overline{H}) - \bar{t} \leq 0$$

In its relationship with the regulator, recall that the firm's costs must be at least as low as what obtains outside the relationship. Because a type θ firm, if does not comply with the standard set by the regulator, bears no liability for any accidents caused by its risky activity, and thus, has no incentive to take care, the right-hand side of the IR constraint is now equal to $\psi(x_N(\theta)) = 0$.

The regulator's problem is, therefore, given by

$$\min_{\{\underline{t},\bar{t},\underline{H},\overline{H},\underline{p},\overline{p},\underline{P},\overline{P}\}} \upsilon\{\beta_1\alpha(\underline{\theta} - \underline{H})\underline{H} + \beta_2\psi(\underline{\theta} - \underline{H}) + \beta_3\lambda\underline{t} + (1 - \beta_1 - \beta_2 - \beta_3)\tau(\underline{p})\}$$
$$+(1 - \upsilon)\{\beta_1\alpha(\overline{\theta} - \overline{H})\overline{H} + \beta_2\psi(\overline{\theta} - \overline{H}) + \beta_3\lambda\bar{t} + (1 - \beta_1 - \beta_2 - \beta_3)\tau(\overline{p})\}$$

subject to the constraints above.

The following proposition summarizes the solution.[21]

[21] There is a vast literature on costly state verification through an audit technology and the solution to this problem is well-known. See, for example, Border and Sobel (1987) provide a careful analysis of the set of binding incentive constraints with a finite number of types. The fundamental problem is that these models lose the Spence-Mirrlees property, and so the incentive-problem with more than two types is badly behaved and quickly becomes intractable as the number of types grows.

Mookherjee and P'ng (1989) analyze an audit problem in an insurance setting. The specficity of their model comes from the fact that the agent is no longer rsik neutral. Risk aversion gives another reason for using a stochastic audit mechanism, namely, increasing the risk exposure of an efficient agent if he lies and mimics an inefficient one.

Khalil (1997) offers a nice treatment of the case without commitment.

Proposition 3 *With audit, the optimal contract entails:*

$$\underline{P} = \psi(\overline{\theta} - \overline{H}) - \psi(\underline{\theta} - \overline{H})$$

Only the inefficient type is audited with a strictly probability $\overline{p}^A$ *such that*

$$(1 - \beta_1 - \beta_2 - \beta_3)\tau'(\overline{p}) = \frac{\nu}{1-v}\lambda\beta_3[\psi(\overline{\theta} - \overline{H}) - \psi(\underline{\theta} - \overline{H})]$$

No output distortion with respect to the first-best outcome for the efficient type, $\underline{s} = s^{IR}(\underline{\theta})$ *and a downward distortion for the less efficient type*

$$-[\beta_1[\alpha'(\overline{\theta} - \overline{H})\overline{H} - \alpha(\overline{\theta} - \overline{H})] + \beta_2\psi'(\overline{\theta} - \overline{H})]$$
$$= \beta_3\lambda\psi'(\overline{\theta} - \overline{H}) + \frac{v}{1-\nu}\beta_3\lambda[(1-\overline{p})(\psi'(\overline{\theta} - \overline{H}) - \psi'(\underline{\theta} - \overline{H}))]$$

The transfers to the type $\overline{\theta}$ *and* $\underline{\theta}$ *firms, respectively, are given by*

$$\overline{t}^A = \psi(\overline{\theta} - \overline{H})$$

$$\underline{t}^A = \psi(\underline{\theta} - \underline{H}) + (1-\overline{p})[\psi(\overline{\theta} - \overline{H}) - \psi(\underline{\theta} - \overline{H})]$$

This solution can be easily contrasted with the equilibrium outcome under incomplete information derived above.

First, supposing that $\tau = c$ for ease of exposition, observe that the equilibrium probability of suit, δ, under *ex post* liability is greater than the probability of a successful audit, p, if the following inequality holds:

$$\psi(\underline{\theta} - \overline{H}) - \psi(\overline{\theta} - \overline{H}) < \Phi(\overline{H}) + \frac{1-\nu}{\nu}\alpha(x_S(\overline{\theta}))(\overline{\theta} - x_S(\overline{\theta}))$$

The greater the punishment, the more likely the regulator will want to incur costs to increase the probability of such punishment. Moreover, under ex post liability where the IR constraint binds, increasing the probability of suit also provides the additional benefit of decreasing the transfer required to satisfy individual rationality. Because the probability of audit does not appear in the corresponding IR constraint, increasing that probability provides no such similar benefit.

Second, observe that the transfer payment with respect to type $\overline{\theta}$ is lower under ex post liability as compared to under an audit since

$$\psi(\overline{\theta} - \overline{H}) > \psi(\overline{\theta} - \overline{H}) - [\psi(x_S(\overline{\theta})) + \overline{\delta}\alpha(x_S(\overline{\theta}))(\overline{\theta} - x_S(\overline{\theta}))]$$

Because strict legal liability is assumed to be the status quo in the case of ex post liability, to induce the firm *not* to reject the contract, the regulator pays less to ensure expected liability costs, which are higher compared to audit where no liability is the status quo and expected liability costs are, thus, equal to 0.

Similarly, the transfer payment with respect to type $\underline{\theta}$ is lower if and only if the following inequality holds:

$$\overline{p}[\psi(\overline{\theta} - \overline{H}) - \psi(\underline{\theta} - \overline{H})] < \overline{\delta}\Phi(\overline{H}) + \psi(x_S(\overline{\theta})) + \overline{\delta}\alpha(x_S(\overline{\theta}))(\overline{\theta} - x_S(\overline{\theta}))$$

The greater the expected liability, $\overline{\delta}\Phi(\overline{H})$, the lower the transfer payment required to induce the firm to choose the contract designed for it. Similarly, the greater the difference in the outside opportunities, $\psi(x_S(\overline{\theta})) + \overline{\delta}\alpha(x_S(\overline{\theta}))(\overline{\theta} - x_S(\overline{\theta}))$, the greater the difference in the transfer payments required to ensure that the contract guarantees costs as least as low as what the firm obtains outside the regulatory relationship.

Third, recall that under ex post liability, the regulator sets marginal expected social costs, $S'(\overline{s}^*)$, such that

$$S'(\overline{s}^*) = -\frac{\beta_3\lambda}{1-v}\{\psi'(\overline{\theta} - \overline{H}^*) - v[\psi'(\underline{\theta} - \overline{H}^*) - \overline{\delta}\Phi'(\overline{H}^*)]\}$$

In the case of audit, by contrast, the regulator sets marginal expected social costs, $S'(\overline{s}^A)$, such that

$$S'(\overline{s}^A) = -\frac{\beta_3\lambda}{1-\nu}\{\psi'(\overline{\theta} - \overline{H}^A) - v[\psi'(\underline{\theta} - \overline{H}^A)) + \overline{p}^A(\psi'(\overline{\theta} - \overline{H}^A) - \psi'(\underline{\theta} - \overline{H}^A))]\}$$

Given that $S(x)$ is convex, $-v\overline{p}^A(\psi'(\overline{\theta} - \overline{H}^A) - \psi'(\underline{\theta} - \overline{H}^A)) < 0 < v\overline{\delta}\Phi'(\overline{H}^*)$ implies $\overline{s}^A > \overline{s}^*$. That is, the downward distortion with respect to the type $\overline{\theta}$ firm under ex post strict liability, $\overline{s}^*$, is greater than the downward distortion for type $\overline{\theta}$ under an audit technology, $\overline{s}^A$.

To interpret, in the case of ex post strict liability, decreasing the regulatory standard, $\overline{s}$, in addition to decreasing the expected rent of type $\underline{\theta}$, has the additional benefit of increasing the punishment imposed when the type $\underline{\theta}$ firm misreports type. In the case of audit, however, decreasing the regulatory standard, or, equivalently, increasing $\overline{H}^A$, decreases the punishment imposed when a false report is detected since $\psi'' > 0$, which, of course, weakens the incentive not to misreport type.

Because of this positive correlation with the level of punishment imposed, downward distortions from the optimal regulatory standard are a more powerful regulatory instrument in the case of ex post strict liability, and the regulator is, therefore, more willing to rely on this particular regulatory instrument to induce optimal levels of precaution than it is where an audit technology is employed. This result is summarized in the following proposition.

Proposition 4 *The downward distortion with respect to the efficient type, where the regulator uses legal liability to punish a false report is greater than the downward distortion, where the regulator uses an audit technology to punish a false report. That is,*

$$\overline{s}^A > \overline{s}^*$$

5.2 The Threat of Capture

The extension considered here is motivated by the observation that because the firm does not face legal liability in accepting the regulatory contract, the regulated firm might not actually find it profitable to exert resources to make it difficult for the regulator to increase the probability of suit; that is, in equilibrium, it might not be the case that $c'(\delta^*) > 0$ (as was assumed in the preceding analysis).

To examine this possibility more formally, suppose that *before* the regulatory contract is offered to the firm, the firm can expend resources, χ, to *capture* the regulator, meaning that the firm can make it more costly for the regulator to increase the probability of suit, δ.[22] Specifically, let the cost of increasing the probability of suit from a pre-existing baseline be given by $kc(\delta)$, with $k \geq 0$.[23] The firm can expend resources to increase k, but assume that it is costly to do so. Let the cost to the firm be given by the function, $\chi(k)$, with $\chi(0) = 0$, $\chi' > 0$, and $\chi'' > 0$.

Assuming that the regulatory contract is accepted by the firm in the next stage of the game (the next stage, the contracting game modelled thus far), the firm solves the following maximization problem

$$\min_k \ \psi(\theta - H(k)) - t(k) + \chi(k)$$

subject to the first-order conditions with respect to $\overline{\delta}$ and $\overline{H}$, respectively,

$$(1 - \beta_1 - \beta_2 - \beta_3)kc'(\overline{\delta}^*(k)) = \frac{1}{1-\nu}[\beta_3 \lambda \nu \Phi(\overline{H}) + \mu_1 \alpha(x_S(\overline{\theta}))(\overline{\theta} - x_S(\overline{\theta}))]$$

$$-S'(\overline{\theta} - \overline{H}^*) = \frac{\beta_3 \lambda}{1-v}\{\psi'(\overline{\theta} - \overline{H}^*) + v(\overline{\delta}\Phi'(\overline{H}^*) - \psi'(\underline{\theta} - \overline{H}^*))\}$$

as well as the following expressions for $\underline{t}^*$ and $\overline{t}^*$:

$$\underline{t}^* = \psi(\underline{\theta} - \underline{H}^*) - \psi(\underline{\theta} - \overline{H}^*) - \overline{\delta}\Phi(\overline{H}^*)$$

and

$$\overline{t}^* = 0$$

or

$$\overline{t}^* = \psi(\overline{\theta} - \overline{H}^*) - [\psi(x_S(\overline{\theta})) + \overline{\delta}\alpha(x_S(\overline{\theta}))(\overline{\theta} - x_S(\overline{\theta}))]$$

depending on whether or not the IR constraint for the type $\overline{\theta}$ firm is binding.

Observe that the first-order conditions with respect to H and δ implicitly define functions: $H(k)$ and $\delta(k)$.[24] To solve for $\overline{\delta}^{*\prime}(k)$ and $\overline{H}^{*\prime}(k)$, substitute the two functions into the above first-order conditions and differentiate each equation with respect to k. That is,

$$\overline{\delta}^{*\prime}(k) = -\frac{c'(\overline{\delta}^*(k))}{kc''(\overline{\delta}^*(k))} + \overline{H}'(k)\frac{\nu\beta_3\lambda\Phi'(\overline{H})}{(1-\beta_1-\beta_2-\beta_3)(1-\nu)kc''(\overline{\delta}^*(k))}$$

[22] Insert a little literature review here.

[23] For any given level of x, the firm can increase the marginal cost of x. Though not fully general, it captures the essential intuition.

[24] Need to say something here about satisfaction of the appropriate second-order conditions.

$$\overline{H}^{*\prime}(k) = \frac{v\Phi'(\overline{H}^*)}{\frac{1-v}{\beta_3\lambda}S''(\overline{\theta}-\overline{H}^*)+\psi''(\overline{\theta}-\overline{H}^*)-v[\overline{\delta}\Phi''(\overline{H}^*)+\psi''(\underline{\theta}-\overline{H}^*)]}\overline{\delta}'(k)$$

Assume[25]

$$\frac{1-v}{\beta_3\lambda}S''(\overline{\theta}-\overline{H}^*)+\psi''(\overline{\theta}-\overline{H}^*)-v[\overline{\delta}\Phi''(\overline{H}^*)+\psi''(\underline{\theta}-\overline{H}^*)] < 0$$

Hence, $\overline{H}^{*\prime}(k)$ can be expressed as

$$\overline{H}^{*\prime}(k) = K\overline{\delta}'(k)$$

where $K < 0$.

Plugging this expression into the first-order condition with respect to $\overline{\delta}$ yields

$$\overline{\delta}^{*\prime}(k) = -\frac{c'(\overline{\delta}^*(k))(1-\beta_1-\beta_2-\beta_3)(1-\nu)kc''(\overline{\delta}^*(k))}{kc''(\overline{\delta}^*(k))(1-\beta_1-\beta_2-\beta_3)(1-\nu)kc''(\overline{\delta}^*(k))-K\nu\beta_3\lambda\Phi'(\overline{H})}$$

Since $c' > 0$, $c'' > 0$, $K < 0$, and $\Phi'(\overline{H}) > 0$, it follows that $\overline{\delta}^{*\prime}(k) < 0$. Making it more costly for the regulator to increase the probability of suit has the straightforward effect of decreasing the equilibrium probability of suit. Moreover, $\overline{H}^{*\prime}(k) > 0$, and thus, $\overline{s}^{*\prime}(k) < 0$. Expending resources to increase the probability of suit decreases the regulatory standard of care, $\overline{s}^*(k)$, accepted by the type $\overline{\theta}$ firm.

To understand how k relates to the transfer payments, substitute $\overline{H}(k)$ and $\overline{\delta}(k)$ into the expressions for $\overline{t}^*$ and $\underline{t}^*$ and differentiate with respect to k. Start with transfer $\overline{t}$ and assume that the IR constraint is binding. Differentiating with respect to k yields

$$\overline{t}^{*\prime}(k) = -\psi'(\cdot)\overline{H}^{*\prime}(k) - \overline{\delta}'(k)\alpha(x_S(\overline{\theta}))(\overline{\theta}-x_S(\overline{\theta}))$$

Note that the inefficient type $\overline{\theta}$ firm expends resources to solve

$$-\psi'(\cdot)H'(\overline{k}) - \overline{t}'(\overline{k}) = -\chi'(\overline{k})$$

Substituting the above expression for $\overline{t}^{*\prime}(k)$,

$$-\psi'(\cdot)H'(\overline{k}) - [-\psi'(\cdot)\overline{H}^{*\prime}(k) - \overline{\delta}'(k)\alpha(x_S(\overline{\theta}))(\overline{\theta}-x_S(\overline{\theta}))] = -\chi'(\overline{k}^*)$$

$$\Longrightarrow \overline{\delta}^{*\prime}(\overline{k})\alpha(x_S(\overline{\theta}))(\overline{\theta}-x_S(\overline{\theta})) = -\chi'(\overline{k}^*)$$

which implies $\overline{k}^* > 0$. That is, the type $\underline{\theta}$ firm will expend positive resources to decrease the probability of suit if the IR constraint is binding. If the IR constraint is *not* binding, however, then $\overline{k}^* = 0$. The firm will not invest in lobbying the regulator.

[25] Maybe say a little something here about this assumption made.

Similarly, differentiating the expression for transfer, $\underline{t}^*$, with respect to k yields

$$\underline{t}^{*\prime}(k) = \psi'(\underline{\theta} - \overline{H}^*(k))\overline{H}^{*\prime}(k) - \overline{\delta}'(k)\Phi(\overline{H}^*(k)) - \overline{\delta}(k)\Phi'(\overline{H}^*)\overline{H}^{*\prime}(k)$$

which implies that the sign of $\underline{t}^{*\prime}(k)$, again, depends on which of two opposing effects dominates. Since k does not have an impact on $\underline{H}$, the efficient type $\underline{\theta}$ firm expends resources to solve

$$\underline{t}^{*\prime}(k) = \chi'(\underline{k}^*)$$

Thus, if $\underline{t}^{*\prime}(\cdot) > 0$, then $\underline{k}^* > 0$, and the type $\underline{\theta}$ firm will expend positive resources to decrease the probability of suit so as to increase the amount of the transfer received. On the other hand, if $\underline{t}^{*\prime}(\cdot) \leq 0$, then $\underline{k}^* = 0$, implying that the firm will *not* expend resources to increase the probability of suit.

These comparative static results are summarized in the following proposition.

Proposition 5 *Suppose that*

$$\frac{1-v}{\beta_3 \lambda} S''(\overline{\theta} - \overline{H}^*) + \psi''(\overline{\theta} - \overline{H}^*) - v[\overline{\delta}\Phi''(\overline{H}^*) + \psi''(\underline{\theta} - \overline{H}^*)] < 0$$

If the IR constraint for the type $\overline{\theta}$ firm is binding, then $\overline{k}^* > 0$. Otherwise, $\overline{k}^* = 0$. Similarly, if

$$\underline{t}^{*\prime}(k) = \psi'(\underline{\theta} - \overline{H}^*(k))\overline{H}^{*\prime}(k) - \overline{\delta}'(k)\Phi(\overline{H}^*(k)) - \overline{\delta}(k)\Phi'(\overline{H}^*)\overline{H}^{*\prime}(k) > 0$$

then $\underline{k}^* > 0$. Otherwise, $\underline{k}^* = 0$.

Hence, under these assumptions, if the IR constraint for the type $\overline{\theta}$ firm is not binding and $\underline{t}^{*\prime}(k) \geq 0$, then the optimal incomplete information outcome calculated in the preceding section is based on a political economy assumption that is *not* consistent with equilibrium behavior. That is, the firms will not expend resources to make it relatively more costly for the regulator to increase the probability of suit, $\overline{\delta}$.

By contrast, if the IR constraint for the type $\overline{\theta}$ firm is binding or $\underline{t}^{*\prime}(k) < 0$, then this inconsistency no longer obtains. As was presumed in the above analysis, firms will lobby or, equivalently, will expend positive resources $k^* > 0$ such that it costly for the regulator to increase the probability of suit, $\overline{\delta}$, even though, in equilibrium, firms do not actually incur legal liability.

6 Conclusion

[*Summarize Results of the Paper*]

References

[1] Boyer, Marcel & Donatella Porrini. (2004). "Modelling the Choice between Regulation and Liability in Terms of Social Welfare." *Canadian Journal of Economics* 37: 590-612.

[2] Calabresi, Guido. (1970). *The Costs of Accidents*. New Haven: Yale University Press.

[3] Diamond, Peter. (1974). "Single Activity Accidents." *Journal of Legal Studies* 3: 107-64.

[4] Ewerhart, Christian & Patrick W. Schmitz. (1998). "*Ex Post* Liability for Harm vs. *Ex Ante* Safety Regulations: Substitutes or Complements?

[5] Comment." *American Economic Review* 88(4): 1027-28.

[6] Hiriart, Yolande, David Martimort, & Jerome Pouyet. (2004). "On the Optimal Use of Ex Ante Regulation and Ex Post Liability." *Economic Letters*. 84: 231-35.

[7] ———. (2006).

[8] Innes, Robert. (2004). "Enforcement Costs, Optimal Sanctions, and the Choice between *Ex Post* Liability and *Ex Ante* Regulation." *International Review of Law and Economics* 24: 29-48.

[9] Khalil, Fahad. (1997). "Auditing without Commitment." *Rand Journal of Economics* 28(4): 629-40.

[10] Kolstad, Charles D., Thomas S. Ulen, & Gary V. Johnson. (1990). "*Ex Post* Liability for Harm vs. *Ex Ante* Safety Regulations: Substitutes or Complements?" *American Economic Review* 80(4): 888-901.

[11] Lewis, T. & D. Sappington. (2000). "Contracting with Wealth-Constrained Agents." *International Economics Review* 41: 743-67.

[12] Mookherjee, Dilip & Ivan Png. (1989). "Optimal Auditing, Insurance, and Redistribution." *Quarterly Journal of Economics* 104: 399-415.

[13] Polinsky, A. Mitchell & Daniel Rubinfeld. (1988). "The Welfare Implications of Costly Litigation for the Level of Liability." *Journal of Legal Studies* 17: 151-164.

[14] ———. (1996). "Optimal Awards and Penalties when the Probability of Prevailing Varies Among Plaintiffs." *Rand Journal of Economics* 27: 269-80.

[15] Riordan, M. & D. Sappington (1988). Optimal Contracts with Public Ex Post Information." *Journal of Economic Theory* 45: 189-99.

[16] Schmitz, Patrick W. (2000). "On the Joint Use of Liability and Safety Regulation." *International Review of Law and Economics* 20: 371-82.

[17] Shavell, Steven. (1984a). "A Model of the Optimal Use of Liability and Safety Regulation." *RAND Journal of Economics* 15(2): 271-80.

[18] ———. (1984b). "Liability for Harm versus Regulation of Safety." *Journal of Legal Studies* 13: 357-74.

[19] ———. (1987). *The Economics of Accident Law.* Cambridge: Harvard University Press.

[20] Weitzman, Martin L. (1974). "Price versus. Quantities." *Review of Economic Studies* 41: 447-91.

[21] Wittman, Donald. (1977). "Prior Regulation versus Post Liability: The Choice between Input and Output Monitoring." *Journal of Legal Studies* 6(1): 193-211.