Regulation Versus Litigation

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Abstract

We compare the efficiency of regulation, litigation, and laissez faire in a model of optimal social control of harmful externalities. In our model, firms choose activity levels in addition to precautions. In contrast to the usual assumptions, we assume that social returns to activity are higher than private returns, even taking externalities into account. Finally, we assume that both courts and regulators make errors in assessing whether it is efficient for a given firm to take precautions. We find that optimal litigation (a negligence rule) typically performs better at incentivizing precautions, while regulation (which optimally offers safe harbor from liability to firms classified as safe) performs better at incentivizing activity. We show how the optimal structure of law enforcement is influenced by the level of harm, the divergence between private and social returns to activity, and the relative competence of regulators and courts.

1 Introduction

The American and European societies are much richer today than they were 100 years ago, yet they are also vastly more regulated. Today, we live in houses and apartment buildings whose construction – from zoning, to use of materials, to fire codes – is heavily regulated. We eat food grown with heavily regulated fertilizers and hormones, processed in heavily regulated factories with publicly monitored technologies, and sold in regulated outlets with elaborate labels and warnings. Our means of transport, including cars, buses, and airplanes, are made, sold, driven, and maintained under heavy government regulation. Our children attend schools where licensed instructors teach heavily regulated curriculae, visit licensed doctors who follow heavily regulated procedures and are paid government-controlled prices, and play on play-grounds built under government mandated safety standards.

Yet despite this self-evident time-series correlation between regulation and welfare, the case for regulation is difficult to make, both theoretically and empirically. Theoretically, straightforward law and economics arguments suggest that a combination of private contracts and efficient tort rules adjudicated by judges generally suffices to restrain harmful acts. As shown by Coase (1960), so long as people whose behavior might affect each other's welfare can sign enforceable contracts, they will agree to efficient conduct. Even if contracting is costly, efficient tort rules would generally restore efficiency. And these rules are not too complex. For example, when harmful conduct by one party can affect another, strict liability in many cases creates incentives for optimal precautions (Becker 1968, Posner 1973, Spence 1977, Shavell 1980). There is no need for regulation.

Empirically, a significant body of research initiated by Stigler (1971) and De Soto (1989) shows that many government regulations are either obtained by the industry seeking protection from competitors, or by government bureaucrats themselves seeking bribes. Regulation not only fails to help, but makes things worse. There seems to be a vast disconnect between the basic theory and evidence and the broad facts outlined in the first paragraph.

In this paper, we seek to contribute to the theory of optimal regulation and litigation. The theory does not address the positive aspects of regulation stressed by Stigler (1971) and De Soto (1990), but seeks to explain some of the stylized facts regarding the areas of activity where regulation might be preferred to litigation. The theory follows the general approach of Becker (1968), Calabresi (1970), and Posner (1972) on the relative desirability from the efficiency perspective of alternative methods of controlling harmful behavior, but introduces some new aspects of the problem. The theory also follows the standard idea that regulation involves ex ante evaluation of whether firms should take precautions, whereas litigation focuses on the ex post evaluation of whether they should have taken them (Shavell 1984a,b). This distinction is very closely related to Kaplow's (1992) distinction between rules and standards.

We are surely not the first to consider the comparison of litigation and regulation in the economic framework. The best developed case for regulation is based on the judgment-proof problem, the idea that, with liability, damages might be so high that the liable firm or individual would be unable to pay them. Under these circumstances, regulation might be optimal (Shavell 1984a,b, 1993, Summers 1983). We do not disagree that the judgment-proof problem is important, although one must remember that it is large corporations, with considerable resources as well as access to insurance that are being regulated. Another economic argument for regulation includes the greater expertise of regulators than of judges (Landis 1938, Glaeser, Johnson, and Shleifer 2001). Still another idea is that judges might be more vulnerable to persuasion and bribery than regulators (Becker and Stigler 1974, Glaeser and Shleifer 2003).

In this paper, we return to what in some ways is a more traditional law and economics framework of comparing regulation, litigation, and laissez-faire, and do not focus on either the judgment proof problem or the incentives of law enforcers. Instead, we make three crucial substantive assumptions, each of which has in some way already been considered by law and economics scholarship.

First, we consider a model in which the structure of penalties affects not just precautions, but also the level of activity. A firm subject to either liability or regulatory fines might thus choose not only its level of precautions, but also whether or not to operate (or to pursue a particular project). Shavell (1980) and Polinsky (1980) have considered activity levels in assessing the optimal liability rules, but not regulation. Viscusi and Moore (1993) theoretically and empirically explore how liability costs may decrease the incentive for firms to innovate.

Second, and most importantly, models of optimal enforcement consider the case where, absent the harmful externalities, the private and social returns to activity are the same, so that, with the externality, private returns to activity are higher than social ones. We reverse this assumption and assume instead that activity is extremely socially desirable (and cannot be subsidized directly) so that, even with the harmful externality, the social returns to activity are higher than the private ones. One can think of the activity as medical procedures, where the doctor does not capture the full social return to saving a life. Or one can think of a polluter who nonetheless runs a factory and pays people above their alternative wage. Or one can think of an entrepreneur or an innovator, whose activity improves a technology, the returns from which he does not fully capture.

This assumption is absolutely critical to making the case for regulation because, as we demonstrate below, it makes activity highly desirable, and litigation might hamper activity more than regulation does. We do not mean to suggest by this assumption that private returns to economic activity are always larger than social ones, though we think that there are many examples where this is true. The point, however, is that this assumption seems to us to be the most natural route for making the efficiency case for regulation. It resonates with the commonly made argument that litigation drives firms out of business or affects the introduction of new products, and this may be bad (Viscusi 1991a). Even readers who do not accept this argument might be interested in understanding the conditions under which the efficiency case for regulation can be made.

In turns out that even the above two assumptions are not sufficient to make the case for regulation: in fact, we show that in a standard model regulation and negligence are equivalent under the above assumptions. So we make an additional third assumption, namely that both regulators and judges make errors in deciding whether a firm should efficiently take precautions. The idea of law enforcers making errors is also not new; Png (1986), Kostad, Ulen, and Johnson (1990), and Polinsky and Shavell (2000) examine the implications of errors in enforcement for optimal fines. Kaplow and Shavell (1996) provide a general analysis of the effects of accuracy in the assessment of damages.

We develop the implications of the above three assumptions in a fairly standard model of optimal law enforcement. In our framework, the optimal liability rule is negligence, whereby a firm has to pay damages if the court finds that it did not take precautions but should have taken them. The optimal regulatory rule is “safe harbor” regulation, whereby a firm that is initially found by the regulator not to need to take precautions is exempt from fines even if an accident occurs as advocated by Viscusi (1991b).

In this framework, we can compare the costs and the benefits of regulation, as compared to litigation and laissez-faire. The cost of regulation is that the regulator subject to error mistakenly grants some firms safe harbor from later fines, and therefore discourages these firms from taking precautions. The benefit of regulation is that the expected dollar value of fines imposed due to error is lower than it is under litigation (Png 1986), which encourages higher levels of socially desirable activity. Put differently, in our model litigation performs better at incentivizing optimal precautions, and regulation performs better at incentivizing optimal activity levels. We develop comparative statics on the various circumstances – from the social benefit of the activity, to harm levels, to the relative competence of courts and regulators – that favor regulation, litigation, or laissez-faire.

Perhaps the closest to our analysis is the observation by Calabresi (1970, p. 270): “Too large a fine or criminal penalty in an area where errors are likely may, as we have already seen, result in individuals abstaining from conduct we do not wish to affect, such as driving in general, for fear that if they drive at all they may occasionally be incorrectly condemned and penalized.” Note that errors are explicitly present in Calabresis quote, and the level of activity is also considered, at least implicitly. Our paper presents a formal model in which, with errors by law enforcers, high penalties resulting from efficient negligence rules might unnecessarily discourage highly socially desirable activity.

In the rest of this introduction, we present a few examples of situations our model is intended to capture. Section 2 presents the basic model. Second 3 introduces enforcement regimes that involve regulators or courts but not both and presents results on optimal litigation and optimal regulation. Section 4 compares the enforcement regimes and examines how the optimal structure of law enforcement is influenced by the level of harm, the divergence between private and social returns to activity, and the relative competence of regulators and courts. Section 5 considers regimes that involve both regulators and courts.

1.1 Examples

Example 1. *Drugs*

A drug company decides

- Whether to bring a drug to market
- Whether to warn physicians of a potential side-effect of taking the drug where
    - For some drugs, the side effect is unlikely given the information known to the drug company
    - For others, the side effect is likely given the information known to the drug company

If the enforcement method involves regulators, then prior to a drug's release a regulator decides whether to require the drug company to warn physicians of a potential side-effect in the process of marketing the drug. If the drug company fails to warn then it may later be penalized.

If the enforcement method involves courts, after an accident occurs, a judge or jury decides whether or not the drug company did and should have warned physicians of a potential side-effect. A plaintiff is awarded damages as a function of these findings.

Example 2. *Production plant*

The owner/operator of a plant decides

- Whether to continue production
- Whether to install a fire door
  - Given the design of some plants the addition of a fire door would not reduce the likelihood that a worker is injured in the case of a fire
  - Given the design of others the addition of a fire door would significantly reduce the likelihood that a worker is injured in the case of a fire

If the enforcement method involves regulators, then prior to the owner's decision of whether to continue production, a regulator decides whether to require the addition of a fire door. If the plant owner fails to install the door then she may later be penalized.

If the enforcement method involves courts, after an accident occurs, a judge or jury decides whether or not the plant owner did and should have installed a fire door. A plaintiff is awarded damages as a function of these findings.

Example 3. *Flying an airplane*

An airline decides

- Whether to fly a plane
- Whether to perform some maintenence operation
  - For some planes, the particular maintenence operation does not affect flight safety
  - For others, the maintenence operation reduces the likelihood of an accident

If the enforcement method involves regulators, then, prior to flying a plane, an airline knows whether a regulator requires that it perform some maintenence operation in order to fly. If the airline does not perform that operation then it may later be penalized.

Under litigation, after an accident occurs, a judge or jury decides whether or not an airline did and should have performed some maintenence operation. A plaintiff is awarded damages as a function of these findings.

2 Model

2.1 Firms

A firm decides whether or not to engage in an activity, $y \in \{0, 1\}$ (whether or not to bring a drug to market, to continue the production of a product, to fly a plane). If it does not engage in activity ($y = 0$) it receives a payoff of 0. If it engages in activity, it receives private gross payoff αb, where $0 \leq \alpha \leq 1$ and b is distributed across firms according to a c.d.f $G(b)$.

If a firm engages in the activity, it also decides on its level of precaution $p \in \{P, NP\}$ (whether or not to warn physicians of a potential side-effect of taking a drug, to install a fire door, to perform some maintenence operation on a plane). Not taking precaution ($p = NP$) is costless. Taking precaution ($p = P$) costs the firm c and may decrease the probability of an accident. The accident imposes a social cost h, which is assumed to be the same for all accidents.

The payoff to the firm if it engages in activity is

$$\alpha b - c_0 - \{\text{costs of precaution} + \text{expected liability costs given precaution}\} \tag{1}$$

where $c_0 > 0$ is the baseline cost of activity. The firm's problem is to choose its level of precaution ($p = P$ or NP) and its activity ($y = 0$ or 1) to maximize

$$(\alpha b - c_0 - \{\text{costs of precaution} + \text{expected liability costs}\})y \tag{2}$$

Firms differ in whether or not taking precaution is efficient. Measure 1 of firms are safe, denoted by S. Whether a firm is safe is independent of b. For a safe firm, the probability of an accident is independent of the level of precaution and equals $\pi_S(p) \equiv \pi_S$. Hence it is socially inefficient for the safe firm to take precaution.

Measure 1 of firms are unsafe, denoted by U. Whether a firm is unsafe is independent of b. For an unsafe firm, the probability of an accident depends on whether or not it takes precaution. If it fails to take precaution, the probability of an accident is $\pi_U(NP) \equiv \pi_U$. If it takes precaution, the probability of an accident is $\pi_U(P) \equiv \pi_U^P < \pi_U$. For algebraic simplicity, set $\pi_U^P = 0$.[1]

We assume that it is socially efficient for an unsafe firm to take precaution:

Assumption 1. $\pi_U h > c$

We also assume that the unsafe firm is more likely than the safe firm to cause an accident if the former does not take precaution

Assumption 2. $0 < \pi_S < \pi_U$

Note that firms differ across two dimensions in our model. They differ in their private benefit to engaging in activity, as parameterized by b, as well as in whether taking precaution is effective, as indicated by their level of safety S or U.

2.2 Society

The gross benefit to society from the firm engaging in activity is b. Since the gross private benefit to the firm is αb, the gross benefit to society is $1/\alpha$ times the gross benefit to the firm. The lower is α, the greater is the positive externality to society from the firm's activity. Examples of activities with low α include entrepreneurial or innovative activities, like new drug development, and certain medical procedures, like drug vaccination.

We make the following substantive assumption regarding externalities associated with firm activity:

Assumption 3. $\alpha \leq \frac{c_0}{c_0+\pi_U h}$

Assumption 3 says that, in the absence of liability rules, the net externality to activity is positive for all firms that engage in activity, so activity is good even absent precaution. Put

[1] The exact choice of π_U^P does not matter for our results. Our results would continue to hold, for instance, if we instead set $\pi_U^P = \pi_S$.

differently, in the absence of liability rules, the positive externality to society of firm activity, $(1-\alpha)b$, outweighs the negative externality, which is at most $\pi_U h$, for all firms that engage in activity.[2]

The social payoff from a firm engaging in activity level $y = 0$ or 1 and choosing precaution $p = P$ or NP is

$$(b - c_0 \quad - \quad \{\text{costs of precaution} + \text{expected harm}\})y \tag{3}$$

2.3 First best

To solve for the first best, we maximize social payoff (3) with respect to activity y and precaution p for each firm. In the first best, a safe firm does not take precaution since, for safe firms, not taking precaution minimizes [costs of precaution + expected harm]. A safe firm engages in activity if

$$\underbrace{b}_{\text{benefit of activity}} > \underbrace{c_0 + \pi_S h}_{\text{minimized costs of activity}} \tag{4}$$

In the first best, an unsafe firm takes precaution since, for unsafe firms, taking precaution minimizes [costs of precaution + expected harm]. An unsafe firm engages in activity if

$$\underbrace{b}_{\text{benefit of activity}} > \underbrace{c_0 + c}_{\text{minimized costs of activity (recall that } \pi_U^P h = 0)} \tag{5}$$

Summing up the net benefit to activity across all firms that engage in activity, welfare in

[2]In the absence of liability rules, $\alpha b \geq c_0$ for all firms that engage in activity so the net externality to engaging in activity is greater than or equal to $(1-\alpha)\frac{c_0}{\alpha} - \pi_U h$ for all firms that engage in activity. Rearranging $(1-\alpha)\frac{c_0}{\alpha} - \pi_U h \geq 0$ to write it in terms of α gives us Assumption 3.

the first best is

$$W^{FB} = \underbrace{\int_{c_0+\pi_S h}^{\infty} b - (c_0 + \pi_S h) dG(b)}_{\equiv W_S^{FB}} + \underbrace{\int_{c_0+c}^{\infty} b - (c_0 + c) dG(b)}_{\equiv W_U^{FB}} \tag{6}$$

Defining *activity level* to equal the number of firms that engage in activity, the first best activity level is

$$\overline{y}^{FB} = \underbrace{(1 - G(c_0 + \pi_S h))}_{\text{activity of safe firms}} + \underbrace{(1 - G(c_0 + c))}_{\text{activity of unsafe firms}} \tag{7}$$

2.4 Laissez-faire

In the absence of liability rules (laissez-faire), each firm maximizes

$$(\alpha b - c_0 \quad - \quad \{\text{costs of precaution}\}) y \tag{8}$$

Under laissez-faire, S (efficiently) does not take precaution since

$$\underbrace{c}_{\text{cost of precaution}} > \underbrace{0}_{\text{liability for failure to take precaution}} \tag{9}$$

and engages in activity if

$$\underbrace{\alpha b}_{\text{benefit}} > \underbrace{c_0}_{\text{cost}} \tag{10}$$

Since, in the absence of liability rules, safe and unsafe firms face the same problem, U (inefficiently) does not take precaution under laissez-faire and engages in activity if $\alpha b > c_0$.

Summing up the net benefit to activity across all firms that engage in activity, welfare under laissez-faire is given by

$$W^{LF} = \underbrace{\int_{\frac{c_0}{\alpha}}^{\infty} b - (c_0 + \pi_S h) dG(b)}_{\equiv W_S^{LF}} + \underbrace{\int_{\frac{c_0}{\alpha}}^{\infty} b - (c_0 + \pi_U h) dG(b)}_{\equiv W_U^{LF}} \tag{11}$$

The activity level under laissez-faire is

$$\overline{y}^{LF} = \underbrace{(1 - G(\frac{c_0}{\alpha}))}_{\text{activity of safe firms}} + \underbrace{(1 - G(\frac{c_0}{\alpha}))}_{\text{activity of unsafe firms}} \tag{12}$$

Both safe and unsafe firms undersupply activity relative to the first best under laissez-faire because, in the absence of liability rules, the net externality from activity is positive for the marginal safe or unsafe firm by Assumption 3. To illustrate, we show that safe firms undersupply activity under laissez-faire. Recall that, in the first best, S engages in activity if $b > c_0 + \pi_S h \equiv \underline{b}_S^{FB}$ but, under laissez-faire, S engages in activity if $b > \frac{c_0}{\alpha} \equiv \underline{b}_S^{LF}$. Since, by Assumption 3, $\underline{b}_S^{LF} > \underline{b}_S^{FB}$, S undersupplies activity under laissez-faire. A similar argument shows that $\underline{b}_U^{LF} > \underline{b}_U^{FB}$, implying that U undersupplies activity under laissez-faire.

Summarizing these results: Under laissez-faire,

- Unsafe firms take inefficiently little precaution and safe firms take first best precaution
- Activity is undersupplied by both unsafe and safe firms

2.5 Enforcement methods

We consider several law enforcement methods implemented by courts or regulators who cannot subsidize firms. These methods provide incentives for unsafe firms to take precaution (unlike laissez-faire) by imposing penalties for failure to do so. However, under Assumption 3, imposing penalties can be costly, since it may raise the cost to engaging in activity and, as a consequence, lower firm activity below an amount that is inefficiently low even in the absence of liability rules.

If the enforcement method involves courts, a case is brought against a firm if and only if it causes an accident. If a case is brought to court, the court can observe whether the firm took precaution as well as a noisy signal σ_J of the firm's type, where

$$\begin{aligned}\text{Prob}[\sigma_J = S|\text{firm's type is U}] &= \epsilon_{S|U} \\ \text{Prob}[\sigma_J = U|\text{firm's type is S}] &= \epsilon_{U|S}.\end{aligned}$$

Here $\epsilon_{S|U}$ and $\epsilon_{U|S}$ represent court errors in determining a firm's type. The court imposes damages $d \geq 0$ as a function of whether the firm took precaution, as well as its signal.

To illustrate, take the drug example. If the enforcement method involves courts, after an accident occurs, a judge or jury decides whether or not the drug company did and should have warned physicians of a potential side-effect (whether the drug company took precaution and a signal of whether it should have taken precaution - its type - respectively). A plaintiff is awarded damages as a function of these findings. We later show that, without loss of generality, the optimal enforcement rule involving courts is negligence, whereby a plaintiff is only awarded damages when the court finds that the drug company did not but should have warned physicians of a potential side-effect of taking the drug.

If the enforcement method involves regulators, prior to a firm's choice of precaution and activity a regulator publicly classifies the firm as unsafe or safe based on signal σ_R, where

$$\begin{aligned}\text{Prob}[\sigma_R = S|\text{firm's type is } U] &= \delta_{S|U} \\ \text{Prob}[\sigma_R = U|\text{firm's type is } S] &= \delta_{U|S}.\end{aligned}$$

A firm is classified as type i if and only if $\sigma_R = i$ for $i = S$ or U. Thus, $\delta_{S|U}$ and $\delta_{U|S}$ represent regulatory errors in firm classification. A regulator can impose a fine $F \geq 0$ as a function of the classification and of whether the firm took precaution, where the fine is levied in the case of an accident. The firm knows the fine schedule prior to its choice of precaution and activity.[3]

To illustrate, again take the drug example. If the enforcement method involves regulators, then *prior* to a drug's release a regulator determines whether the drug company should warn physicians of a potential side-effect in the process of marketing the drug. If the drug company fails to warn then it may later be penalized as a function of the regulator's decision. We later show that, without loss of generality, the optimal enforcement method involving regulators takes the form of "safe-harbor regulation", where the drug company can be penalized for failure to warn physicians if and only if the drug is classified as unsafe.

Both courts and regulators are vulnerable to making errors in determining whether a firm is safe or unsafe. The main difference between courts and regulators is that courts make a determination of firm type *ex post* (after a firm's choice of activity and precaution), whereas regulators make that determination *ex ante* (prior to a firm's choice of activity and precaution). Later we show that, all else equal, this difference implies that, without loss of generality, litigation is better at incentivizing unsafe firms to take precaution and regulation is better at incentivizing more activity.

We assume that errors cannot be "too large" or, equivalently, that court and regulatory signals are informative

Assumption 4. $0 \leq \epsilon_{S|U} < 1/2,\ 0 \leq \epsilon_{U|S} < 1/2, 0 \leq \delta_{S|U} < 1/2,\ 0 \leq \delta_{U|S} < 1/2$

To limit the number of cases considered and to keep the problem interesting, we assume that, absent subsidies, the net effect on social welfare of requiring unsafe firms to take precaution is positive (taking into account the effects on both precaution and activity):

Assumption 5. $\int_{\frac{c_0+c}{\alpha}}^{\infty} b - (c_0 + c)dG(b) > \int_{\frac{c_0}{\alpha}}^{\infty} b - (c_0 + \pi_U h)dG(b)$

When Assumption 5 does not hold, laissez-faire is always optimal.

Summarizing,the timing of the model:

[3] Many of our results are qualitatively unchanged if the fine can be levied prior to an accident.

- Period 0: Under regulation, a firm is classified as unsafe or safe by a regulator. This classification is subject to error.

- Period 1: A firm (which knows its true type S or U) decides whether to engage in activity ($y \in \{0, 1\}$) and whether to take precaution ($p \in \{P, NP\}$)

- Period 2: An accident may occur in which case

  - Under regulation, a regulator may charge some fine $F \geq 0$

  - Under litigation, a court finds a firm to be safe or unsafe and may charge some damage award $d \geq 0$. The court's finding is subject to error.

2.5.1 Second best

Given the enforcement methods we consider, welfare cannot be higher than under a hypothetical benevolent social planner who can directly observe a firm's type and choose its level of precaution but not its level of activity.[4] Outcomes under this hypothetical planner serve as the relevant benchmark for assessing the performance of alternative enforcement methods. We label the planner's choice *second best*.

Such a planner would dictate that safe firms not take precaution since taking precaution is costly and the probability of an accident is independent of safe firms' level of precaution. A safe firm chooses to engage in activity if

$$\underbrace{\alpha b}_{\text{benefit of activity}} > \underbrace{c_0}_{\text{cost of activity}} \tag{13}$$

The planner would dicate that unsafe firms take precaution since, by Assumption 5, the welfare gain that results from reducing the probability that unsafe firms cause an accident if

[4] In principle, while these enforcement methods cannot incentivize firms to increase activity beyond the level chosen under this hypothetical planner, they can incentivize firms to decrease activity below this amount through penalties. However, such a decrease in activity is inefficient by Assumption 3, so the outcomes under this hypothetical planner are the relevant benchmark.

they engage in activity outweighs the direct costs of precaution plus losses that result from decreasing the number of unsafe firms that engage in activity. An unsafe firm chooses to engage in activity if

$$\underbrace{\alpha b}_{\text{benefit of activity}} > \underbrace{c_0 + c.}_{\text{cost of activity plus precaution}} \tag{14}$$

Summing up the net benefit to activity across all firms that engage in activity, welfare under the second best is given by

$$W^{SB} = \underbrace{\int_{\frac{c_0}{\alpha}}^{\infty} b - (c_0 + \pi_S h) dG(b)}_{\equiv W_S^{SB}} + \underbrace{\int_{\frac{c_0+c}{\alpha}}^{\infty} b - (c_0 + c) dG(b)}_{\equiv W_U^{SB}} \tag{15}$$

Activity level under the second best is given by

$$\overline{y}^{SB} = \underbrace{\left(1 - G\left(\frac{c_0}{\alpha}\right)\right)}_{\text{activity of safe firms}} + \underbrace{\left(1 - G\left(\frac{c_0 + c}{\alpha}\right)\right)}_{\text{activity of unsafe firms}} \tag{16}$$

3 Enforcement regimes

Consider the following regimes that involve regulators or courts but not both:[5]

1. *Laissez-faire* (defined as above).

2. *Negligence.* Under negligence

   - A firm that causes harm is required to pay damages d whenever

     - It is found to have not taken precaution

     - It is found to be unsafe

   - Taking into account errors that a court makes *ex post* in determining a firm's

[5] Later, we explore regimes that involve some combination of regulators and courts.

type, damages d are the minimum necessary to incentivize unsafe firms to take precaution

3. *Safe-harbor regulation.* Under safe-harbor regulation

   - Firms are publicly classified as unsafe or safe based on a classification technology
   - Each firm that is classified as unsafe is investigated in the case of an accident and is charged $F_U > 0$ if caught not taking precaution, where F_U is the minimum fine necessary to incentivize unsafe firms classified as unsafe to take precaution
   - Each firm that is classified as safe is never charged a fine
   - Each firm knows its classification as well as the fine schedule prior to choosing whether to take precaution and its activity level.

Lemma 1. *Consider law enforcement regimes that involve regulators or courts but not both. Under Assumptions 1-5, laissez-faire, negligence, or safe-harbor regulation maximizes social welfare. Further, restricting attention to regimes that never penalize firms if they take precaution, only laissez-faire, negligence, or safe-harbor regulation can maximize social welfare for generic court and regulatory errors.*

With respect to litigation, Lemma 1 implies that strict liability (under which a firm that causes an accident always pays damages) is never optimal.[6] In addition, the optimal damage award under negligence is the minimum necessary to incentivize unsafe firms to take precaution. As we discuss in greater detail below, the basic reason why negligence always performs better than strict liability in our model is as follows. Compared to strict liability, negligence encourages greater activity among safe firms because, under negligence, such firms face comparatively lower expected liability costs. This greater activity translates into welfare gains due to our assumption of a positive net externality from firm activity in the absence of liability rules (Assumption 3). This assumption also drives our result that

[6] Limiting attention to enforcement regimes that never penalize firms if they take precaution is without loss of generality in the sense that one such regime is always optimal (though perhaps not uniquely).

the optimal damage award under negligence is the minimum necessary to incentivize unsafe firms to take precaution.

With respect to regulation, Lemma 1 says that it is never optimal to impose a fine on firms classified as safe for failure to take precaution. In addition, the optimal fine for firms classified as unsafe is the minimum necessary to incentivize precaution among the correctly classified unsafe firms. The intuition for why optimal regulation has the feature of granting safe harbor to firms classified as safe is as follows. As shown below, negligence incentivizes second best precaution for all firms and second best activity for unsafe firms. Consequently, regulation can only do better than negligence if it encourages safe firms to engage in more activity. At a minimum, this requires setting a fine for firms classified as safe that is lower than the minimum necessary to incentivize precaution among the unsafe firms mistakenly classified as safe. A fine of zero is clearly optimal since, in this range, lowering the fine encourages greater (and more efficient) activity by Assumption 3, while bringing out the same level of precaution. Assumption 3 also drives our result that, under regulation, the optimal fine for firms classified as unsafe is the minimum necessary to incentivize precaution among the correctly classified unsafe firms.

To illustrate the contrast between negligence and safe-harbor regulation (which, from now on, we abbreviate as regulation), return to the drug example. Under negligence, after an accident occurs, a judge or jury decides both whether the drug company did and whether it should have warned physicians of a potential side-effect. A plaintiff is awarded damages if the court decides (possibly incorrectly) that the drug company should have warned but failed to do so.

Under regulation, *prior* to a drug's release, a regulator decides whether to require the drug company to warn physicians of a potential side-effect in the process of marketing the drug. If the regulator decides that the drug company does not need to warn physicians then, under regulation, the drug company cannot later be penalized for failure to warn. On the other hand, if the regulator finds that the drug company should warn physicians (possibly incorrectly), but the company fails to do so, then it is charged a penalty in the event of an accident.

Before we examine negligence and regulation in more detail, we note that, in the absence of court or regulatory errors in determining firm type, both regulation and negligence achieve the second best outcome. To see this, following the definition of negligence, let the damage award be equal to the minimum necessary to incentivize unsafe firms to take precaution

$$\underbrace{c}_{\text{cost of precaution}} = \underbrace{\pi_U d}_{\text{expected liability if no precaution}} \Rightarrow \tag{17}$$

$$\tag{18}$$

$$d = \frac{c}{\pi_U} \tag{19}$$

Likewise, following the definition of regulation, let the fine for firms classified as unsafe (which would apply to all unsafe firms in the absence of regulatory errors) be equal to the minimum necessary to incentivize precaution

$$c = \pi_U F_U \Rightarrow \tag{20}$$

$$F_U = \frac{c}{\pi_U} \tag{21}$$

With no errors, and $d = F_U = \frac{c}{\pi_U}$, both negligence and regulation achieve the second best outcome. To see this, note that, under either regime, a safe firm makes the same decisions as under the second best: it does not take precaution because

$$\underbrace{c}_{\text{cost of precaution}} > \underbrace{0}_{\text{liability if no precaution}} \tag{22}$$

and engages in activity if

$$\underbrace{\alpha b}_{\text{benefit of activity}} > \underbrace{c_0}_{\text{cost of activity}} \tag{23}$$

In addition, under either regime, an unsafe firm makes the same decisions as under the second best: it takes precaution by construction of d and F_U and engages in activity if

$$\underbrace{\alpha b}_{\text{benefit of activity}} > \underbrace{c_0 + c}_{\text{cost of activity plus precaution}} \tag{24}$$

Thus, in our model, any difference in the relative performance of negligence and regulation must result from errors by courts and/or regulators in determining firm type.

Proposition 1. *If courts and regulators do not make errors,* $\epsilon_{S|U} = \delta_{S|U} = \epsilon_{U|S} = \delta_{U|S} = 0$*, then negligence and regulation achieve the second best outcome and, as a result, perform better than laissez faire.*

Next we consider the performance of negligence and regulation in the presence of court and regulatory error.

3.1 Negligence

Under negligence, an unsafe firm that engages in activity optimally chooses to take precaution if and only if

$$\underbrace{c}_{\text{cost of precaution}} \leq \underbrace{\pi_U(1 - \epsilon_{S|U})d}_{\text{expected liability cost if no precaution}} \tag{25}$$

By Lemma 1, the optimal damage award under negligence is the minimum necessary to incentivize unsafe firms to take precaution. It is found by setting d such that (25) holds with equality

$$c = \pi_U(1 - \epsilon_{S|U})d^* \Rightarrow \tag{26}$$

$$d^* = \frac{c}{(1 - \epsilon_{S|U})\pi_U} \tag{27}$$

When $d = d^*$, a safe firm optimally chooses *not* to take precaution. This is because

d^* is set at a value that makes the unsafe firm indifferent between taking and not taking precaution given its likelihood of causing an accident and being found to be unsafe. Since the safe firm is less likely to both cause an accident and be found unsafe, with damages d^* the safe firm strictly prefers not taking precaution:

$$\underbrace{c}_{\text{cost of precaution}} > \underbrace{\pi_S \epsilon_{U|S} d^*}_{\text{expected liability cost if no precaution}} \tag{28}$$

where the inequality follows from

$$c = \pi_U (1 - \epsilon_{S|U}) d^* > \pi_S \epsilon_{U|S} d^*$$

Proposition 2. *The level of damages in a negligence regime is given by*

$$d^* = \frac{c}{(1 - \epsilon_{S|U}) \pi_U} \tag{29}$$

which is increasing in

1. *The likelihood that unsafe firms are mistakenly found not liable,* $\epsilon_{S|U}$
2. *The cost of precaution,* c
3. *The probability that unsafe firms do not cause an accident if they fail to take precaution,* $1 - \pi_U$

Since, under negligence, damages are such that safe firms do not engage in precaution, they are exposed to liability costs due to court errors. Such firms engage in activity if

$$\underbrace{\alpha b}_{\text{benefit}} > \underbrace{c_0 + \pi_S \epsilon_{U|S} d^*}_{\text{cost of activity plus liability}} \tag{30}$$

Hence, the activity level of safe firms under negligence is

$$\overline{y}_S^N = \left(1 - G\left(\frac{c_0 + \pi_S \epsilon_{U|S} d^*}{\alpha}\right)\right) \tag{31}$$

which is lower than the second best activity level $(1 - G(\frac{c_0}{\alpha}))$ and is decreasing in d^*.

Since, under negligence, damages are such that unsafe firms engage in precaution, they are not exposed to liability costs by Lemma 1. Such firms engage in activity if

$$\underbrace{\alpha b}_{\text{benefit}} > \underbrace{c_0 + c}_{\text{cost of activity plus precaution}} \tag{32}$$

Hence, the level of activity of such firms under negligence is

$$\overline{y}_U^N = \left(1 - G\left(\frac{c_0 + c}{\alpha}\right)\right) \tag{33}$$

which equals the second best level.

Summarizing these results: Under negligence,

- All firms take second best precaution
- Unsafe firms' activity level is second best and is independent of the size of damages d^* because such firms avoid paying damages by taking precaution
- Safe firms' activity level is (weakly) lower than second best and, because such firms do not take precaution, is decreasing in damages so long as courts sometimes mistakenly classify safe firms to be unsafe ($\epsilon_{U|S} > 0$)

Summing up the net benefit to activity across all firms that engage in activity, welfare under negligence, W^N, is given by

$$W^N = \underbrace{\int_{\frac{c_0 + \pi_S \epsilon_{U|S} d^*}{\alpha}}^{\infty} b - (c_0 + \pi_S h) dG(b)}_{\equiv W_S^N} + \underbrace{\int_{\frac{c_0 + c}{\alpha}}^{\infty} b - (c_0 + c) dG(b)}_{\equiv W_U^N}$$

3.1.1 An aside: strict liability

At this point, it is worth explaining in more detail why negligence always performs better than strict liability in our model. Assume that, under strict liability, a firm has to pay damages $d = d^{SL}$ whenever it causes an accident (damages are independent of whether the firm took precaution and the signal of its type), where d^{SL} is the minimum damage award necessary to incentivize unsafe firms to take precaution[7]

$$c = \pi_U d^{SL} \Rightarrow d^{SL} = \frac{c}{\pi_U} \tag{34}$$

It is easy to show that welfare under strict liability is

$$W^{SL} = \underbrace{\int_{\frac{c_0+\pi_S d^{SL}}{\alpha}}^{\infty} b-(c_0+\pi_S h)dG(b)}_{\equiv W_S^{SL}} + \underbrace{\int_{\frac{c_0+c}{\alpha}}^{\infty} b-(c_0+c)dG(b)}_{\equiv W_U^{SL}} \tag{35}$$

The difference between welfare under negligence and under strict liability results only from safe firms facing different liability costs under the two regimes (the behavior of unsafe firms is the same under the two regimes):

$$W^N - W^{SL} = \int_{\frac{c_0+\pi_S \epsilon_{U|S} d^*}{\alpha}}^{\frac{c_0+\pi_S d^{SL}}{\alpha}} b-(c_0+\pi_S h)dG(b) \tag{36}$$

$$> 0 \tag{37}$$

where the inequality follows from two facts. First, expected liability costs for safe firms are lower under negligence than under strict liability because, under negligence, safe firms'

[7] This is the optimal damage award under strict liability whenever the optimal such award is positive. In other words, this is the optimal damage award under strict liability whenever strict liability performs better than laissez-faire.

escape liability whenever courts correctly identify them as safe

$$\pi_S d^{SL} - \pi_S \epsilon_{U|S} d^* = \frac{\pi_S c}{\pi_U}\left[1 - \frac{\epsilon_{U|S}}{1-\epsilon_{S|U}}\right] \tag{38}$$

$$> 0 \tag{39}$$

Second, higher liability costs lead to lower activity which, in turn, lead to welfare losses by Assumption 3.

Why does negligence perform better than strict liability under the assumptions of our model but not under the assumptions of more standard models of optimal tort rules (e.g., Shavell 1980)? The answer is our assumption of a positive net externality from firm activity (Assumption 3). An implication of this assumption is that any decrease in safe firms' activity level from the level obtained in the absence of liability rules leads to welfare losses because the net externality to activity is positive. In the more standard models, a sizeable decrease in safe firms' activity level from the level obtained in the absence of liability rules leads to welfare gains because the net externality from activity is negative. In those models, in the absence of liability rules, safe firms fully internalize the social benefit to activity, $\alpha = 1$, but not the expected harm from accidents stemming from the activity, $\pi_S h > 0$. In fact, when $\alpha = 1$ (a value not covered under our assumptions), strict liability with $d^{SL} = h$ achieves the first best in our model as well.

3.2 Regulation

Recall from Lemma 1 that each firm *ex ante* classified as safe is never charged a fine in the case of an accident. Also recall from Lemma 1 that, whenever regulation performs better than laissez-faire, the optimal fine for firms classified as unsafe, F_U, is the minimum necessary to incentivize precaution among the correctly classified unsafe firms:

$$\underbrace{c}_{\text{cost of precaution}} = \underbrace{\pi_U F_U^*}_{\text{expected fine if no precaution}} \Rightarrow \tag{40}$$

$$F_U^* = \frac{c}{\pi_U} \tag{41}$$

Proposition 3. *The level of fines for firms classified as unsafe under regulation is given by*

$$F_U^* = \frac{c}{\pi_U} \tag{42}$$

which is increasing in

1. *The cost of precaution, c*

2. *The probability that unsafe firms do not cause an accident if they fail to take precaution, $1 - \pi_U$*

Corollary 1. *The level of fines for firms classified as unsafe under regulation is lower than damages under negligence:*

$$F_U^* = (1 - \epsilon_{S|U})d^* \leq d^* \tag{43}$$

The reasoning behind Corollary 1 is straightforward and follows from the fact that firms are classified *ex ante* under regulation but *ex post* under litigation. To compensate for the fact that unsafe firms are mistakenly found not liable with probability $\epsilon_{S|U}$ *ex post* under litigation but not under regulation, the minimum (*ex post*) liability necessary to incentivize unsafe firms to take precaution under litigation, d^*, is higher than that under regulation, F_U^*, by a factor of $\frac{1}{1-\epsilon_{S|U}} > 1$. As we will show later, one implication of this result is that the activity level of safe firms tends to be greater under regulation than under negligence.

Consider unsafe firms classified as unsafe under regulation. If such a firm engages in activity, it efficiently chooses to take precaution by construction of F_U^* since

$$\underbrace{c}_{\text{cost of precaution}} = \underbrace{\pi_U F_U^*}_{\text{expected liability cost if no precaution}} \tag{44}$$

and engages in activity if

$$\underbrace{\alpha b}_{\text{benefit}} > \underbrace{c_0 + c}_{\text{cost of activity plus precaution}}$$

Hence, the level of activity of unsafe firms classified as unsafe is

$$\left(1 - G\left(\frac{c_0 + c}{\alpha}\right)\right)$$

which is the second best level.

Now consider safe firms classified as unsafe under regulation. If such a firm engages in activity, it efficiently chooses *not* to take precaution since

$$\underbrace{c}_{\text{cost of precaution}} > \underbrace{\pi_S F_U^*}_{\text{expected liability cost if no precaution}} \tag{45}$$

and engages in activity if

$$\underbrace{\alpha b}_{\text{benefit}} > \underbrace{c_0 + \pi_S F_U^*}_{\text{cost of activity plus expected fine}} \tag{46}$$

Hence, the level of activity of safe firms classified as unsafe is

$$\left(1 - G\left(\frac{c_0 + \pi_S F_U^*}{\alpha}\right)\right) \tag{47}$$

which is lower than the second best and is decreasing in F_U^*.

Finally, consider firms classified as safe under regulation. Since $F_S = 0$ by Lemma 1, firms classified as safe behave as they do under laissez faire.

Summarizing these results: Under regulation,

- Consider firms classified as unsafe
  - All firms (both safe and unsafe) take first best levels of precaution
  - Unsafe firms' level of activity is independent of the level of fines (since they always avoid paying fines by taking precaution) and is at the second best level
  - Safe firms' activity is lower than under the second best and, because such firms do not take precaution, is decreasing in factors that increase $\pi_S F_U^* = \pi_S \frac{c}{\pi_U}$
- Consider firms classified as safe
  - Unsafe firms take less precaution than under the first and second best; safe firms take first best precaution
  - Safe firms' activity is at the second best level; unsafe firms' activity is optimal given their failure to take precaution and the inability of regulators to subsidize activity

Summing up the net benefit to activity across all firms that engage in activity, welfare under regulation is given by

$$W^R = \underbrace{(1-\delta_{U|S})\int_{\frac{c_0}{\alpha}}^{\infty} b-(c_0+\pi_S h)dG(b) + \delta_{U|S}\int_{\frac{c_0+\pi_S F_U^*}{\alpha}}^{\infty} b-(c_0+\pi_S h)dG(b)}_{\equiv W_S^R}$$
$$+ \underbrace{(1-\delta_{S|U})\int_{\frac{c_0+c}{\alpha}}^{\infty} b-(c_0+c)dG(b) + \delta_{S|U}\int_{\frac{c_0}{\alpha}}^{\infty} b-(c_0+\pi_U h)dG(b)}_{\equiv W_U^R}$$

4 Comparing enforcement regimes

We now compare the regimes. For simplicity, we specialize to the case where $b \sim U[0, \overline{b}]$ and $\overline{b} > \frac{c_0+c}{\alpha}$.[8]

First we compare firm behavior under the three regimes.

Proposition 4. *Comparing precaution under the three regimes:*

- *Safe firms always take efficient precaution*
- *Under laissez faire, unsafe firms take too little precaution*
- *Under negligence, unsafe firms take efficient precaution*
- *Under regulation, fraction* $1 - \delta_{S|U}$ *of unsafe firms that are correctly classified take efficient precaution and fraction* $\delta_{S|U}$ *of unsafe firms that are incorrectly classified as safe take too little precaution*

Proposition 5. *Assume that regulators are not too much worse than courts at correctly classifying safe firms as safe,* $\delta_{U|S} \leq \frac{\epsilon_{U|S}}{1-\epsilon_{S|U}}$ *and that* $b \sim U[0, \overline{b}]$*. Then, granting the inability of courts or regulators to subsidize activity,*

- *Unsafe firms always engage in efficient activity given their level of precaution*
- *Under laissez-faire, safe firms engage in efficient activity*
- *Under negligence, safe firms engage in inefficiently low activity*
- *Under regulation, safe firms engage in moderate activity (lower than under laissez-faire but greater than under negligence)*

Proposition 4 says that negligence is better than regulation and regulation is better than laissez-faire at providing incentives for unsafe firms to take precaution. This result is intuitive. Under negligence, each unsafe firm optimally takes precaution because it faces a large

[8] The uniform distribution enables relatively clean results because its c.d.f is a linear function of b.

expected penalty if it chooses not to do so. Under regulation, each unsafe firm correctly classified as unsafe optimally takes precaution because it faces a large expected penalty for failure to do so, but each unsafe firm incorrectly classified as safe does not take precaution because it is granted safe harbor. Last, under laissez-faire, each unsafe firm optimally chooses not to take precaution because it faces no penalty for failure to do so (it is effectively granted safe harbor).

Proposition 5 says that laissez-faire is better than regulation and regulation is better than negligence at encouraging safe firms to engage in activity whenever regulators are not too much worse than courts at correctly identifying safe firms as safe, $\delta_{U|S} \leq \frac{\epsilon_{U|S}}{1-\epsilon_{S|U}}$. The fact that laissez-faire is best at encouraging safe firms to engage in activity is obvious since the cost to engaging in activity is the lowest under laissez-faire.

The fact that regulation is better than negligence at encouraging safe firms to engage in activity is less obvious and follows from the following facts. First, safe firms never take precaution but are exposed to penalties under both regulation and negligence due to errors in classification. Second, activity is linear and decreasing in expected penalties. Third, safe firms face lower expected penalties for failure to take precaution under regulation on average.

The third fact is important and follows from the result of Corollary 1 that damages under negligence are higher than fines for firms classified as unsafe under regulation by a factor of $\frac{1}{1-\epsilon_{S|U}} > 1$. So long as $\delta_{U|S} \leq \frac{\epsilon_{U|S}}{1-\epsilon_{S|U}}$, this result implies that safe firms face lower expected penalties for failure to take precaution under regulation *on average*:[9]

$$(1-\delta_{U|S}) * 0 + \delta_{U|S} * \pi_S F_U^* \leq \pi_S \epsilon_{U|S} d^* \iff \quad (48)$$

$$\pi_S \delta_{U|S} \frac{c}{\pi_U} \leq \pi_S \epsilon_{U|S} \frac{c}{\pi_U(1-\epsilon_{S|U})} \iff \quad (49)$$

$$\delta_{U|S} \leq \frac{\epsilon_{U|S}}{1-\epsilon_{S|U}} \quad (50)$$

[9] Note that higher average activity among safe firms under regulation does not necessarily imply that $W_S^R > W_S^N$. The reason is that $\frac{1}{\bar{b}} \int_{\frac{c_0+\chi}{\alpha}}^{\bar{b}} b - (c_0 + \pi_S h) db$ is concave in expected penalties, χ.

The results of Propositions 4 and 5 are summarized in Figure 1.

	Laissez faire	Regulation	Negligence
Safe firms' activity	Best	Middle	Worst
Unsafe firms' precaution	Worst	Middle	Best

Figure 1: Illustration of Propositions 4 and 5

Proposition 6. *Assume that $b \sim U[0, \bar{b}]$, fix all parameters other than h, and let $\underline{h}$ and $\overline{h}$ be the minimum and maximum values of h such that Assumptions 1 - 5 are satisfied. Then there exist two cutoffs h_1 and h_2 satisfying $\underline{h} < h_1 \leq h_2 \leq \overline{h}$ such that the following characterizes the optimal regime as a function of the size of harm resulting from an accident:*

1. *Negligence is optimal for high values of h: $W^N > \max\{W^R, W^{LF}\}$ for $h \in (h_2, \overline{h})$*

2. *Regulation is optimal for middle values of h: $W^R > \max\{W^N, W^{LF}\}$ for $h \in (h_1, h_2)$*

3. *Laissez-faire is optimal for low values of h: $W^{LF} > \max\{W^R, W^N\}$ for $h \in (\underline{h}, h_1)$*

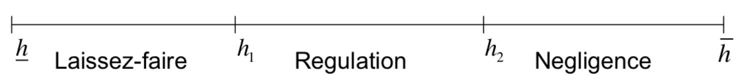

Figure 2: Illustration of Proposition 6

Proposition 7. *Define h_1 and h_2 as above and suppose parameter values are such that $\underline{h} < h_1 < h_2 < \overline{h}$.*

1. *An increase in the expertise of regulators increases the likelihood that regulation is optimal and decreases the likelihood that negligence or laissez-faire is optimal: For $\delta_{i|j} \in \{\delta_{U|S}, \delta_{S|U}\}$, $-\frac{\partial(h_2 - h_1)}{\partial \delta_{i|j}} > 0, -\frac{\partial(\bar{h} - h_2)}{\partial \delta_{i|j}} < 0$, and $-\frac{\partial(h_1 - \underline{h})}{\partial \delta_{i|j}} < 0$.*

2. *An increase in the expertise of courts increases the likelihood that negligence is optimal and decreases the likelihood that regulation is optimal: For* $\epsilon_{i|j} \in \{\epsilon_{U|S}, \epsilon_{S|U}\}$, $-\frac{\partial(\overline{h}-h_2)}{\partial \epsilon_{i|j}} > 0$ *and* $-\frac{\partial(h_2-h_1)}{\partial \epsilon_{i|j}} < 0$.

Proposition 8. *Assume that* $b \sim U[0, \bar{b}]$, *fix all parameters other than* α, *and let* $\underline{\alpha}$ *and* $\overline{\alpha}$ *be the minimum and maximum values of* α *such that Assumptions 1 - 5 are satisfied. Then there exist two cutoffs* α_1 *and* α_2 *satisfying* $\underline{\alpha} < \alpha_1 \leq \alpha_2 \leq \overline{\alpha}$ *such that the following characterizes the optimal regime as a function of the extent to which each firm internalizes the gross social benefit to engaging in activity:*

1. *Negligence is optimal for high values of* α: $W^N > \max\{W^R, W^{LF}\}$ *for* $\alpha \in (\alpha_2, \overline{\alpha})$
2. *Regulation is optimal for middle values of* α: $W^R > \max\{W^N, W^{LF}\}$ *for* $\alpha \in (\alpha_1, \alpha_2)$
3. *Laissez-faire is optimal for low values of* α: $W^{LF} > \max\{W^R, W^N\}$ *for* $\alpha \in (\underline{\alpha}, \alpha_1)$

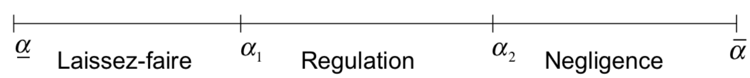

Figure 3: Illustration of Proposition 8

Proposition 9. *Define* α_1 *and* α_2 *as above and assume that parameter values are such that* $\underline{\alpha} < \alpha_1 < \alpha_2 < \overline{\alpha}$.

1. *An increase in the expertise of regulators increases the likelihood that regulation is optimal and decreases the likelihood that negligence or laissez-faire is optimal: For* $\delta_{i|j} \in \{\delta_{U|S}, \delta_{S|U}\}$, $-\frac{\partial(\alpha_2-\alpha_1)}{\partial \delta_{i|j}} > 0, -\frac{\partial(\bar{\alpha}-\alpha_2)}{\partial \delta_{i|j}} < 0$, *and* $-\frac{\partial(\alpha_1-\underline{\alpha})}{\partial \delta_{i|j}} < 0$.
2. *An increase in the expertise of courts increases the likelihood that negligence is optimal and decreases the likelihood that regulation is optimal: For* $\epsilon_{i|j} \in \{\epsilon_{U|S}, \epsilon_{S|U}\}$, $-\frac{\partial(\overline{\alpha}-\alpha_2)}{\partial \epsilon_{i|j}} > 0$ *and* $-\frac{\partial(\alpha_2-\alpha_1)}{\partial \epsilon_{i|j}} < 0$.

From the above propositions, we see that:

1. Negligence is more likely to be optimal when

   - The size of harm that may result from firm activity is large, implying that the net externality to firm activity is low and the efficacy of precaution for unsafe firms is large (the efficacy of precaution can be thought of as being measured by $\pi_U h$).
   - Firms internalize much of the gross social benefit to engaging in activity.
   - Courts are relatively good at distinguishing safe and unsafe firms.

2. Regulation is more likely to be optimal when

   - The size of harm that may result from firm activity lies in a middle range, implying that the net externality to firm activity as well as the efficacy of precaution for unsafe firms lies in a middle range.
   - Firms internalize a moderate amount of the gross social benefit to engaging in activity.
   - Regulators are relatively good at distinguishing between safe and unsafe firms.

3. Laissez-faire is more likely to be optimal when

   - The size of harm that may result from firm activity is low, implying that the net externality to firm activity is large and the efficacy of precaution for unsafe firms is low.
   - Firms do not internalize much of the gross social benefit to engaging in activity.
   - Regulators and courts are not very good at distinguishing safe and unsafe firms.

5 Combination of regulators and courts

So far we have compared enforcement regimes that involve regulators or courts but not both. Now we consider regimes that involve both regulators and courts.

Specifically, we consider regimes that combine regulators and courts in the following way. Prior to a firm's choice of precaution and activity, a regulator publicly classifies the firm as unsafe or safe by reporting its signal σ_R. If the firm causes an accident a case is brought to court. At this time the court can observe whether the firm took precaution, a signal σ_J of the firm's type, and the regulatory classification σ_R. The court then imposes damages $d \geq 0$ as a function of whether the firm took precaution, its signal, *and* the regulatory classification.[10]

To illustrate, return to the drug example. Prior to a drug's release a regulator determines whether the drug company should warn physicians of a potential side-effect in the process of marketing the drug. If an accident occurs, a case against the drug company is brought to court. A judge or jury then determines whether or not the drug company did and should have warned physicians of a potential side-effect, taking into account both new evidence on the drug's safety as well as the regulator's previous classification. A plaintiff is awarded damages as a function of these findings. Note that we allow the damage award to ignore the regulator's classification (pure litigation), new evidence (equivalent to pure regulation), or both (laissez-faire).

For simplicity, we assume that regulators and courts observe independent signals conditional on a firm's type:

Assumption 6. *$Prob[\sigma_R = r, \sigma_J = j|$firm's type$] = Prob[\sigma_R = r|$firm's type$] * Prob[\sigma_J = j|$firm's type$]$ for all $r = S$ or U and $j = S$ or U*

Consider the following regime that involves both regulators and courts:

Safe-harbor negligence. Under safe-harbor negligence

- Firms are publicly classified as unsafe or safe based on a classification technology
- Each firm that is classified as unsafe is required to pay damages d whenever
    - It is found to have not taken precaution

[10] It is not important that the court (rather than a regulator) can impose a penalty in the case of an accident. It is important, however, that the penalty can be set taking into account the regulatory classification together with the court's signal.

- The court's signal indicates that it is unsafe

- Taking into account errors that a court makes *ex post* in determining a firm's type, damages for firms classified as unsafe are the minimum necessary to incentivize unsafe firms correctly classified as unsafe to take precaution

- Each firm that is classified as safe never has to pay damages

Lemma 2. *Consider law enforcement regimes that involve regulators, courts, or both. Under Assumptions 1-6, laissez-faire, negligence, or safe-harbor negligence maximizes social welfare. Further, restricting attention to regimes that never penalize firms if they take precaution, only laissez-faire, negligence, or safe-harbor negligence can maximize social welfare for generic court and regulatory errors.*

With respect to regimes that require the use of both regulators and courts, Lemma 2 implies that it is never optimal to impose a penalty on firms classified as safe for failure to take precaution. In other words, if a regime that requires the use of both regulators and courts is optimal then a firm should be immune from liability if it can demonstrate compliance with the regulatory standard (as advocated by Viscusi, 1991b). The intuition is as follows. Recall that negligence incentivizes second best precaution for all firms and second best activity for unsafe firms. Consequently, a regime that involves the use of both regulators and courts can only do better than negligence if it encourages safe firms to engage in more activity. At a minimum, this requires setting a penalty for firms classified as safe that is lower than the minimum necessary to incentivize precaution among the unsafe firms mistakenly classified as safe. A penalty of zero is clearly optimal since, in this range, lowering the fine encourages greater (and more efficient) activity by Assumption 3, while bringing out the same level of precaution.

Lemma 2 also implies that it is never generically optimal for a regime to only involve regulators when it is possible to combine the use of courts. In fact, it is easy to show that so long as regulators sometimes mistake safe firms for being unsafe ($\delta_{U|S} > 0$) safe-harbor negligence achieves strictly higher welfare than regulation.[11] The reason is that expected liability costs for safe firms mistakenly classified as unsafe are lower under safe-harbor negligence than under regulation because, under safe-harbor negligence, safe firms escape liability whenever courts correctly identify them as safe. The lower liability costs lead to higher activity which, in turn, lead to welfare gains by Assumption 3.

Considering this larger class of regimes, we can prove analogs to Propositions 6, 7, 8, and 9 by replacing regulation with safe-harbor negligence.

The results we get in considering this larger class of regimes are analogous to our earlier results. Negligence typically performs better at incentivizing precaution, while safe harbor negligence performs better at incentivizing activity. Negligence is more likely to be optimal for high levels of harm, when the divergence between private and social returns to activity are low, and when court errors are small. Safe harbor negligence is more likely to be optimal for middle levels of harm, when the divergence between private and social returns to activity is moderate, and when regulatory errors are small. Last, laissez-faire is more likely to be optimal for low levels of harm, when the divergence between private and social returns to activity is large, and when court and regulatory errors are significant.

[11] The difference in welfare is $\delta_{U|S}\left[\int_{\frac{c_0+\pi_S\frac{c}{\pi_U}\frac{\epsilon_{U|S}}{1-\epsilon_{S|U}}}{\alpha}}^{\frac{c_0+\pi_S\frac{c}{\pi_U}}{\alpha}} b-(c_0+\pi_S h)dG(b)\right]\geq 0$ with strict inequality if and only if $\delta_{U|S}>0$.

A Proofs

Proof of Lemma 1. For ease of notation, define

$$\hat{p} = \begin{cases} 1 & \text{if } p = P \\ 0 & \text{if } p = NP \end{cases} \tag{51}$$

First consider regimes that only involve courts. To find the set of damage functions $d(\sigma_J, \hat{p}) \geq 0$ (or $d : \{S, U\}\text{x}\{0, 1\} \to \mathbb{R}^+$) that may be optimal, we consider the following maximization problem:

$$\max_{d(\cdot)\geq 0} W^d \tag{MC}$$

subject to

$$W^d = \underbrace{\int_{\frac{c_0+\pi_S[(1-\epsilon_{U|S})d(S,\hat{p}_S)+\epsilon_{U|S}d(U,\hat{p}_S)]+\hat{p}_S c}{\alpha}}^{\infty} b - (c_0 + \hat{p}_S c + \pi_S h) dG(b)}_{\equiv W_S} \tag{52}$$

$$+ \underbrace{\int_{\frac{c_0+\pi_U(\hat{p}_U)[(1-\epsilon_{S|U})d(U,\hat{p}_U)+\epsilon_{S|U}d(S,\hat{p}_U)]+\hat{p}_U c}{\alpha}}^{\infty} b - (c_0 + \hat{p}_U c + \pi_U(\hat{p}_U)h) dG(b)}_{\equiv W_U}$$

$$\hat{p}_i = \arg\max_{\hat{p}'_i} -(c\hat{p}'_i + \pi_i(\hat{p}'_i)[(1-\epsilon_{-i|i})d(i, \hat{p}'_i) + \epsilon_{-i|i}d(-i, \hat{p}'_i)]) \tag{53}$$

$$\text{for } i = S \text{ and } U, \text{ where } -S = U \text{ and } -U = S$$

Let $d^*(\cdot)$ denote a solution to (MC) and $\hat{p}^*_S$ and p^*_U denote the level of precaution taken by safe and unsafe firms under $d^*(\cdot)$. We now characterize $d^*(\cdot)$ through a series of claims.

Claim 1. $\hat{p}^*_S = 0$

Proof. Suppose $\hat{p}^*_S = 1$. If, in addition, $\hat{p}^*_U = 1$ then we could set $d^*(S, 0) = 0$ and $d^*(U, 0) =$

$\frac{c}{(1-\epsilon_{S|U})\pi_U}$ which would not affect W_U but would increase W_S by

$$\int_{\frac{c_0+\frac{\pi_S\epsilon_{U|S}c}{(1-\epsilon_{S|U})\pi_U}}{\alpha}}^{\frac{c_0+c}{\alpha}} b-(c_0+\pi_S h)dG(b)>0$$

contradicting the optimality of d^*. Note that the inequality follows from $\frac{\pi_S\epsilon_{U|S}c}{(1-\epsilon_{S|U})\pi_U}<c$ together with Assumption 3.

Now suppose that $\hat{p}_U^*=0$. Then we could set $d^*(S,0)=d^*(U,0)=0$ which would (weakly) increase W_U and would strictly increase W_S by Assumption 3 together with the assumption that $\pi_S(1)=\pi_S$. □

Claim 2. *If $\hat{p}_U^*=0$ then $d^*(S,0)=d^*(U,0)=0$.*

Proof. Suppose that $\hat{p}_U^*=0$ but that $d^*(j,0)>0$ for some $j\in\{S,U\}$. Then could lower $d^*(j,0)$ to zero which would increase W_S and W_U by Assumption 3, thereby contradicting the optimality of $d^*(\cdot)$. □

Claim 3. *If $\hat{p}_U^*=1$ then $d^*(S,0)=0$. Further, $d^*(U,0)=\frac{c}{(1-\epsilon_{S|U})\pi_U}$ if $\epsilon_{U|S}>0$ and W^d is constant in $d(U,0)\geq\frac{c}{(1-\epsilon_{S|U})\pi_U}$ if $\epsilon_{U|S}=0$.*

Proof. Suppose $\hat{p}_U^*=1$. If $d^*(S,0)>0$ then we could lower $d^*(S,0)$ by $0<\Delta\leq d^*(S,0)$ and raise $d^*(U,0)$ by $\frac{\epsilon_{S|U}}{1-\epsilon_{S|U}}$ which would not affect W_U but would lower expected liability costs for safe firms by $-\Delta[\epsilon_{U|S}\frac{\epsilon_{S|U}}{1-\epsilon_{S|U}}-(1-\epsilon_{U|S})]>0$ and increase W_S by Assumption 3. Hence $d^*(S,0)=0$.

Since $\hat{p}_U^*=1$ and $d^*(S,0)=0$, it must be the case that $d^*(U,0)\geq\frac{c}{(1-\epsilon_{S|U})\pi_U}$. If $d(U,0)>\frac{c}{(1-\epsilon_{S|U})\pi_U}$ then we could lower $d(U,0)$ by $0<\Delta\leq d(U,0)-\frac{c}{(1-\epsilon_{S|U})\pi_U}$ which would not affect W_U but would increase W_S by

$$\int_{\frac{c_0+\epsilon_{U|S}(d-\Delta)}{\alpha}}^{\frac{c_0+\epsilon_{U|S}d}{\alpha}} b-(c_0+\pi_S h)dG(b)\geq 0$$

with strict inequality whenever $\epsilon_{U|S}>0$. Hence, for $\epsilon_{U|S}>0$, $d^*(U,0)=\frac{c}{(1-\epsilon_{S|U})\pi_U}$. □

Claim 4. *If* $(d(S,0), d(U,0), d(S,1), d(U,1))$ *is a solution to* (MC) *then so is* $(d(S,0), d(U,0), 0, 0)$

Proof. Let $(d(S,0), d(U,0), d(S,1), d(U,1))$ be a solution to (MC). Then by earlier Claims (i) $d(S,0) = d(U,0) = 0$, (ii) $d(S,0) = 0$, $\epsilon_{U|S} > 0$ and $d(U,0) = \frac{c}{(1-\epsilon_{S|U})\pi_U}$, or (iii) $d(S,0) = 0$, $\epsilon_{U|S} = 0$ and $d(U,0) \geq \frac{c}{(1-\epsilon_{S|U})\pi_U}$.

In each of these cases, W^d is constant in $d(S,1)$ and $d(U,1)$. □

From Claims 1 - 4, we've established that there is always a solution to (MC) with $d(S,1) = d(U,1) = 0$ and

$$(d(S,0), d(U,0)) \in \left\{(0,0), \left(0, \frac{c}{(1-\epsilon_{S|U})\pi_U}\right)\right\} \equiv D_0 \tag{54}$$

.

Moreover, if $\epsilon_{U|S} > 0$ then, for all $d^*(\cdot)$,

$$(d^*(S,0), d^*(U,0)) \in \left\{(0,0), \left(0, \frac{c}{(1-\epsilon_{S|U})\pi_U}\right)\right\} \tag{55}$$

.

Next consider regimes that only involve regulators. To find the set of fine schedules $F(\sigma_R, \hat{p}) \geq 0$ (or $F : \{S, U\}\text{x}\{0,1\} \to \mathbb{R}^+$) that may be optimal, we consider the following maximization problem:

$$\max_{F(\cdot)\geq 0} W^F \tag{MR}$$

subject to

$$W^F = \underbrace{(1-\delta_{U|S})\int_{\frac{c_0+\pi_S F(S,\hat{p}_{S|S})+\hat{p}_{S|S}c}{\alpha}}^{\infty} b-(c_0+\hat{p}_{S|S}c+\pi_S h)dG(b)}_{\equiv W_{S|S}} \tag{56}$$

$$+\underbrace{\delta_{U|S}\int_{\frac{c_0+\pi_S F(U,\hat{p}_{U|S})+\hat{p}_{U|S}c}{\alpha}}^{\infty} b-(c_0+\hat{p}_{U|S}c+\pi_S h)dG(b)}_{\equiv W_{U|S}}$$

$$+\underbrace{(1-\delta_{S|U})\int_{\frac{c_0+\pi_U(\hat{p}_{U|U})F(U,\hat{p}_{U|U})+\hat{p}_{U|U}c}{\alpha}}^{\infty} b-(c_0+\hat{p}_{U|U}c+\pi_U(\hat{p}_{U|U})h)dG(b)}_{\equiv W_{U|U}} \tag{57}$$

$$+\underbrace{\delta_{S|U}\int_{\frac{c_0+\pi_U(\hat{p}_{S|U})F(S,\hat{p}_{S|U})+\hat{p}_{S|U}c}{\alpha}}^{\infty} b-(c_0+\hat{p}_{S|U}c+\pi_U(\hat{p}_{S|U})h)dG(b)}_{\equiv W_{S|U}}$$

$$\hat{p}_{j|i} = \arg\max_{\hat{p}'_{j|i}} -(c\hat{p}'_{j|i}+\pi_i(\hat{p}'_{j|i})F(j,\hat{p}'_{j|i})) \tag{58}$$

$$\text{for } i,j = S \text{ and } U.$$

Let $F^*(\cdot)$ denote a solution to (MR) and $\hat{p}^*_{j|i}$ denote the level of precaution taken by a type i firm classified as j under $F^*(\cdot)$. We now characterize $F^*(\cdot)$ through a series of claims.

Claim 5. *$\hat{p}^*_{j|S} = 0$ for $j \in \{S,U\}$.*

Proof. The proof is analagous to the proof of Claim 1. □

Claim 6. *If $\hat{p}^*_{j|U} = 0$ then $F^*(j,0) = 0$ for $j \in \{S,U\}$.*

Proof. The proof is analagous to the proof of Claim 2. □

Claim 7. *If $\hat{p}^*_{U|S} = 1$ then $F^*(U,0) = \frac{c}{\pi_U}$. If $\hat{p}^*_{U|U} = 1$ then $F^*(U,0) = \frac{c}{\pi_U}$ if $\delta_{U|S} > 0$ and W^F is constant in $F(U,0) \geq \frac{c}{\pi_U}$ if $\delta_{U|S} = 0$.*

Proof. The proof is closely related to the proof of Claim 3. □

Claim 8. *If $\hat{p}^*_{U|U} = 0$ then $\hat{p}^*_{S|U} = 0$*

Proof. Suppose $\hat{p}^*_{U|U} = 0$. This implies that

$$\begin{aligned}
&(1-\delta_{S|U})\int_{\frac{c_0}{\alpha}}^{\infty} b-(c_0+\pi_U h)dG(b)+\delta_{U|S}\int_{\frac{c_0}{\alpha}}^{\infty} b-(c_0+\pi_S h)dG(b) \\
&> (1-\delta_{S|U})\int_{\frac{c_0+c}{\alpha}}^{\infty} b-(c_0+c)dG(b)+\delta_{U|S}\int_{\frac{c_0+\pi_S\frac{c}{\pi_U}}{\alpha}}^{\infty} b-(c_0+\pi_S h)dG(b) \Rightarrow \\
&\delta_{U|S}\left[\int_{c_0/\alpha}^{(c_0+\pi_S/\pi_U c)/\alpha} b-(c_0+\pi_S h)dG(b)\right] \\
&> (1-\delta_{S|U})\left[\int_{(c_0+c)/\alpha}^{\infty} b-(c_0+c)dG(b)-\int_{c_0/\alpha}^{\infty} b-(c_0+\pi_U h)dG(b)\right]
\end{aligned}$$

Thus,

$$\begin{aligned}
&(1-\delta_{U|S})\left[\int_{c_0/\alpha}^{(c_0+\pi_S/\pi_U c)/\alpha} b-(c_0+\pi_S h)dG(b)\right] \\
&> \delta_{S|U}\left[\int_{(c_0+c)/\alpha}^{\infty} b-(c_0+c)dG(b)-\int_{c_0/\alpha}^{\infty} b-(c_0+\pi_U h)dG(b)\right]
\end{aligned}$$

so $\hat{p}^*_{S|U} = 0$. □

Claim 9. *If* $(F(S,0),F(U,0),F(S,1),F(U,1))$ *is a solution to* (MC) *then so is* $(F(S,0),F(U,0),0,0)$

Proof. The proof is essentially the same as the proof of Claim 4. □

From Claims 5 - 9, we've established that there is always a solution to (MR) with $F(S,1) = F(U,1) = 0$ and

$$(F(S,0),F(U,0)) \in \left\{(0,0),\left(0,\frac{c}{\pi_U}\right),\left(\frac{c}{\pi_U},\frac{c}{\pi_U}\right)\right\} \tag{59}$$

.

Moreover, if $\delta_{U|S} > 0$ then, for all $F^*(\cdot)$,

$$(F^*(S,0),F^*(U,0)) \in \left\{(0,0),\left(0,\frac{c}{\pi_U}\right),\left(\frac{c}{\pi_U},\frac{c}{\pi_U}\right)\right\} \tag{60}$$

.

From (54) and (59) we've established that laissez-faire, negligence, safe-harbor regulation, or regulation with $F(S,0) = F(U,0) = c/\pi_U$ is optimal. Further, from (55) and (60)we've established that if $\epsilon_{U|S} > 0$ and $\delta_{U|S} > 0$ then, restricting attention to regimes that never penalize firms if they take precaution, only laissez-faire, negligence, safe-harbor regulation, or regulation with $F(S,0) = F(U,0) = c/\pi_U$ can maximize social welfare.

The last step of the proof is to establish that welfare under negligence is higher than welfare under regulation with $F(S,0) = F(U,0) = \frac{c}{\pi_U}$ so we can ignore such a regulatory regime.

Claim 10. *Welfare under negligence is always higher than welfare under regulation with* $(F(S,0), F(U,0)) = (c/\pi_U, c/\pi_U)$.

Proof. The difference between welfare under negligence and welfare under regulation with $(F(S,0), F(U,0)) = (c/\pi_U, c/\pi_U)$ is

$$\int_{\frac{c_0 + \frac{\pi_S \epsilon_{U|S} c}{(1-\epsilon_{S|U})\pi_U}}{\alpha}}^{\frac{c_0 + \frac{\pi_S c}{\pi_U}}{\alpha}} b - (c_0 + \pi_S h) dG(b) > 0 \tag{61}$$

where the inequality follows from Assumption 3 and the fact that $\frac{\pi_S \epsilon_{U|S} c}{(1-\epsilon_{S|U})\pi_U} < \frac{\pi_S c}{\pi_U}$. □

■

Proof of Propositions 6 and 7. Fix all parameters other than h. First note that, given other parameter values, the domain of h is limited by Assumptions 1, 3, and 5. Assumption 1 is satisfied if and only if $h > c/\pi_U$. Assumption 3 is satisfied if and only if $h \leq \frac{c_0(1-\alpha)}{\pi_U \alpha}$. Assumption 5 is satisfied if and only if

$$\int_{\frac{c_0+c}{\alpha}}^{\infty} b - (c_0 + c) dG(b) > \int_{\frac{c_0}{\alpha}}^{\infty} b - (c_0 + \pi_U h) dG(b) \iff \tag{62}$$

$$h > \frac{2\alpha c(\bar{b}\alpha - 2c_0 - c) + c(2c_0 + c)}{2\alpha(\bar{b}\alpha - c_0)\pi_U} \tag{63}$$

Noting that the right hand side of 63 is less than c/π_U, all assumptions are satisfied if and only if

$$\underline{h} \equiv \frac{2\alpha c(\bar{b}\alpha - 2c_0 - c) + c(2c_0 + c)}{2\alpha(\bar{b}\alpha - c_0)\pi_U} < h \leq \frac{c_0(1-\alpha)}{\pi_U \alpha} \equiv \bar{h} \tag{64}$$

Note that, for this to be feasible, we need $\underline{h} < \overline{h}$ or

$$\bar{b} > \frac{[(1-\alpha)c_0 - \alpha c][2c_0 + 2c] + c^2}{2\alpha[(1-\alpha)c_0 - \alpha c]} \tag{65}$$

$W^N > W^R$ if and only if

$$\underbrace{\int_{\frac{c_0+\pi_S\epsilon_{U|S}d^*}{\alpha}}^{\infty} b - (c_0 + \pi_S h) dG(b)}_{=W_S^N} + \underbrace{\int_{\frac{c_0+c}{\alpha}}^{\infty} b - (c_0 + c) dG(b)}_{=W_U^{SB}} >$$

$$\underbrace{(1-\delta_{U|S})\int_{\frac{c_0}{\alpha}}^{\infty} b - (c_0 + \pi_S h) dG(b)}_{=W_S^{SB}} + \underbrace{\delta_{U|S}\int_{\frac{c_0+\pi_S F_U^*}{\alpha}}^{\infty} b - (c_0 + \pi_S h) dG(b)}_{\equiv \underline{W}_S^R}$$

$$+ \underbrace{(1-\delta_{S|U})\int_{\frac{c_0+c}{\alpha}}^{\infty} b - (c_0 + c) dG(b)}_{=W_U^{SB}} + \underbrace{\delta_{S|U}\int_{\frac{c_0}{\alpha}}^{\infty} b - (c_0 + \pi_U h) dG(b)}_{=W_U^{LF}} \iff$$

$$\delta_{S|U}(W_U^{SB} - W_U^{LF}) > (1-\delta_{U|S})W_S^{LF} + \delta_{U|S}\underline{W}_S^R - W_S^N \iff$$

$$\frac{\delta_{S|U}}{\alpha\bar{b}}\left[(\pi_U h - c)(\bar{b}\alpha - c_0 - c) - \frac{c}{2\alpha}(2c_0 + c - \alpha(c_0 + \pi_U h))\right]$$

$$> \frac{1}{2\bar{b}\alpha^2}\left[(2c_0 - 2\alpha(c_0 + \pi_S h))(\pi_S\epsilon_{U|S}d^* - \pi_S\delta_{U|S}F_U^*) + (\pi_S\epsilon_{U|S}d^*)^2 - \delta_{U|S}(\pi_S F_U^*)^2\right] \iff$$

$$h[2\alpha\{\delta_{S|U}\pi_U(\bar{b}\alpha - c_0) + \pi_S(\pi_S\epsilon_{U|S}d^* - \pi_S\delta_{U|S}F_U^*)\}]$$

$$> \delta_{S|U}c[2\alpha(\bar{b}\alpha - 2c_0 - c) + 2c_0 + c] + 2c_0(1-\alpha)[\pi_S\epsilon_{U|S}d^* - \pi_S\delta_{U|S}F_U^*] + \pi_S^2[(\epsilon_{U|S}d^*)^2 - \delta_{U|S}(F_U^*)^2] \iff$$

$$h > \frac{\delta_{S|U}c[2\alpha(\alpha\bar{b} - 2c_0 - c) + 2c_0 + c] + 2c_0(1-\alpha)[\pi_S\epsilon_{U|S}d^* - \pi_S\delta_{U|S}F_U^*] + \pi_S^2[(\epsilon_{U|S}d^*)^2 - \delta_{U|S}(F_U^*)^2]}{2\alpha[\delta_{S|U}\pi_U(\bar{b}\alpha - c_0) + \pi_S(\pi_S\epsilon_{U|S}d^* - \pi_S\delta_{U|S}F_U^*)]}$$

$$\equiv h_2^1 \tag{*}$$

$W^R > W^{LF}$ if and only if

$$\underbrace{(1-\delta_{U|S})\int_{\frac{c_0}{\alpha}}^{\infty} b-(c_0+\pi_S h)dG(b)}_{=W_S^{SB}}+\underbrace{\delta_{U|S}\int_{\frac{c_0+\pi_S F_U^*}{\alpha}}^{\infty} b-(c_0+\pi_S h)dG(b)}_{\equiv \underline{W}_S^R}$$

$$+\underbrace{(1-\delta_{S|U})\int_{\frac{c_0+c}{\alpha}}^{\infty} b-(c_0+c)dG(b)}_{=W_U^{SB}}+\underbrace{\delta_{S|U}\int_{\frac{c_0}{\alpha}}^{\infty} b-(c_0+\pi_U h)dG(b)}_{=W_U^{LF}}$$

$$>\underbrace{\int_{\frac{c_0}{\alpha}}^{\infty} b-(c_0+\pi_S h)dG(b)}_{\equiv W_S^{LF}}+\underbrace{\int_{\frac{c_0}{\alpha}}^{\infty} b-(c_0+\pi_U h)dG(b)}_{\equiv W_U^{LF}} \iff$$

$$(1-\delta_{S|U})(W_U^{SB}-W_U^{LF}) > \delta_{U|S}(W_S^{LF}-\underline{W}_S^R) \iff$$

$$\frac{(1-\delta_{S|U})}{2\alpha^2\bar{b}}[2\alpha(\pi_U h-c)(\bar{b}\alpha-c_0-c)-c(2c_0+c-2\alpha(c_0+\pi_U h))]$$

$$>\frac{\delta_{U|S}\pi_S F_U^*}{2\alpha^2\bar{b}}[2c_0+\pi_S F_U^*-2\alpha(c_0+\pi_S h)] \iff$$

$$h>\frac{(1-\delta_{S|U})c[2\alpha(\bar{b}\alpha-2c_0-c)+2c_0+c]+\delta_{U|S}\pi_S F_U^*[2c_0+\pi_S F_U^*-2\alpha c_0]}{2\alpha[(1-\delta_{S|U})\pi_U(\bar{b}\alpha-c_0)+\delta_{U|S}\pi_S^2 F_U^*]}$$

$$\equiv h_1^1 \qquad (**)$$

$W^N > W^{LF}$ if and only if

$$\underbrace{\int_{\frac{c_0+\pi_S\epsilon_{U|S}d^*}{\alpha}}^{\infty} b-(c_0+\pi_S h)dG(b)}_{\equiv W_S^N} + \underbrace{\int_{\frac{c_0+c}{\alpha}}^{\infty} b-(c_0+c)dG(b)}_{\equiv W_U^{SB}}$$

$$> \underbrace{\int_{\frac{c_0}{\alpha}}^{\infty} b-(c_0+\pi_S h)dG(b)}_{\equiv W_S^{LF}} + \underbrace{\int_{\frac{c_0}{\alpha}}^{\infty} b-(c_0+\pi_U h)dG(b)}_{\equiv W_U^{LF}} \iff$$

$$W_U^{SB} - W_U^{LF} > W_S^{LF} - W_S^N \iff$$

$$\frac{1}{2\alpha^2\bar{b}}[2\alpha(\pi_U h - c)(\bar{b}\alpha - c_0 - c) - c(2c_0 + c - 2\alpha(c_0+\pi_U h))]$$

$$> \frac{\pi_S\epsilon_{U|S}d^*}{2\alpha^2\bar{b}}[2c_0 + \pi_S\epsilon_{U|S}d^* - 2\alpha(c_0+\pi_S h)] \iff$$

$$h > \frac{c[2\alpha(\bar{b}\alpha - 2c_0 - c) + 2c_0 + c] + \pi_S\epsilon_{U|S}d^*[2c_0(1-\alpha) + \pi_S\epsilon_{U|S}d^*]}{2\alpha[\pi_U(\bar{b}\alpha - c_0) + \pi_S^2\epsilon_{U|S}d^*]}$$

$$\equiv h_2^2 \qquad (***)$$

If $h_1^1 < \min\{h_2^1, \bar{h}\}$ then let $h_2 = \min\{h_2^1, \bar{h}\}$ and $h_1 = h_1^1$. Otherwise, let $h_1 = h_2 = \min\{h_2^2, \bar{h}\}$.

By construction, $\underline{h} < h_1 \leq h_2 \leq \bar{h}$ and, from (*), (**), and (***)

1. Negligence is optimal for high values of h: $W^N > \max\{W^R, W^{LF}\}$ for $h \in (h_2, \overline{h})$
2. Regulation is optimal for middle values of h: $W^R > \max\{W^N, W^{LF}\}$ for $h \in (h_1, h_2)$
3. Laissez-faire is optimal for low values of h: $W^{LF} > \max\{W^R, W^N\}$ for $h \in (\underline{h}, h_1)$

Now suppose parameter values are such that $\underline{h} < h_1 < h_2 < \bar{h}$. Then we have

$$h_2 = h_2^1$$
$$= \frac{\delta_{S|U}c[2\alpha(\alpha\bar{b} - 2c_0 - c) + 2c_0 + c] + 2c_0(1-\alpha)[\pi_S\epsilon_{U|S}d^* - \pi_S\delta_{U|S}F_U^*] + \pi_S^2[(\epsilon_{U|S}d^*)^2 - \delta_{U|S}(F_U^*)^2]}{2\alpha[\delta_{S|U}\pi_U(\bar{b}\alpha - c_0) + \pi_S(\pi_S\epsilon_{U|S}d^* - \pi_S\delta_{U|S}F_U^*)]}$$

$$h_1 = h_1^1$$
$$= \frac{(1-\delta_{S|U})c[2\alpha(\bar{b}\alpha - 2c_0 - c) + 2c_0 + c] + \delta_{U|S}\pi_S F_U^*[2c_0 + \pi_S F_U^* - 2\alpha c_0]}{2\alpha[(1-\delta_{S|U})\pi_U(\bar{b}\alpha - c_0) + \delta_{U|S}\pi_S^2 F_U^*]}$$

From the derivation of h_2, we see that h_2 is defined by the equation

$$\begin{aligned}F(\cdot) \equiv 2\alpha\delta_{S|U}(\pi_U h - c)(\bar{b}\alpha - c_0 - c) - \delta_{S|U}c(2c_0 + c - \alpha(c_0 + \pi_U h)) \\ -(2c_0 - 2\alpha(c_0 + \pi_S h))(\pi_S \epsilon_{U|S} d^* - \pi_S \delta_{U|S} F_U^*) - (\pi_S \epsilon_{U|S} d^*)^2 + \delta_{U|S}(\pi_S F_U^*)^2 \\ = 0\end{aligned}$$

We have

$$\begin{aligned}\frac{\partial F}{\partial h} &= 2\alpha\delta_{S|U}\pi_U(\bar{b}\alpha - c_0 - c) + \delta_{S|U}c\alpha\pi_U + 2\alpha\pi_S(\pi_S\epsilon_{U|S}d^* - \pi_S\delta_{U|S}F_U^*) \\ &> 0 \text{ (since } \bar{b}\alpha - c_0 - c > 0 \text{ and } h_2 > h_1 \text{ implies } d^* > F_U^*) \\ \frac{\partial F}{\partial \delta_{S|U}} &= 2\alpha(\pi_U h - c)(\bar{b}\alpha - c_0 - c) - c(2c_0 + c - \alpha(c_0 + \pi_U h)) \\ &> 0 \text{ (since } W_U^{SB} > W_U^{LF} \text{ by Assumption 5)} \\ \frac{\partial F}{\partial \delta_{U|S}} &= (2c_0 - 2\alpha(c_0 + \pi_S h))\pi_S F_U^* + (\pi_S F_U^*)^2 \\ &> 0 \text{ (since } c_0 > \alpha(c_0 + \pi_S h) \text{ by Assumption 3)} \\ \frac{\partial F}{\partial \epsilon_{U|S}} &= -(2c_0 - 2\alpha(c_0 + \pi_S h))\pi_S d^* - 2(\pi_S d^*)^2\epsilon_{U|S} \\ &< 0 \\ \frac{\partial F}{\partial \epsilon_{S|U}} &= -(2c_0 - 2\alpha(c_0 + \pi_S h))\pi_S\epsilon_{U|S}\frac{\partial d^*}{\partial \epsilon_{S|U}} - 2(\pi_S\epsilon_{U|S})^2 d^* \frac{\partial d^*}{\partial \epsilon_{S|U}} \\ &< 0\end{aligned}$$

Since $\frac{\partial h_2}{\partial x} = \frac{-\partial F/\partial x}{\partial F/\partial h}$, the above calculations establish that $\partial h_2/\partial \delta_{S|U} < 0, \partial h_2/\partial \delta_{U|S} < 0, \partial h_2/\partial \epsilon_{U|S} > 0$, and $\partial h_2/\partial \epsilon_{S|U} > 0$.

From the derivation of h_1 we see that h_1 is defined by the equation

$$\begin{aligned} H(\cdot) \equiv (1-\delta_{S|U})[2\alpha(\pi_U h - c)(\bar{b}\alpha - c_0 - c) - c(2c_0 + c - 2\alpha(c_0 + \pi_U h))] \\ -\delta_{U|S}\pi_S F_U^*[2c_0 + \pi_S F_U^* - 2\alpha(c_0 + \pi_S h)] \\ = 0 \end{aligned}$$

We have

$$\begin{aligned} \frac{\partial H}{\partial h} &= (1-\delta_{S|U})[2\alpha\pi_U(\bar{b}\alpha - c_0 - c) + 2\alpha c\pi_U] + 2\alpha\delta_{U|S}\pi_S F_U^*\pi_S \\ &> 0 \\ \frac{\partial H}{\partial \delta_{S|U}} &= -[2\alpha(\pi_U h - c)(\bar{b}\alpha - c_0 - c) - c(2c_0 + c - 2\alpha(c_0 + \pi_U h))] \\ &< 0 \\ \frac{\partial H}{\partial \delta_{U|S}} &= -\pi_S F_U^*[2c_0 + \pi_S F_U^* - 2\alpha(c_0 + \pi_S h)] \\ &< 0 \end{aligned}$$

Since $\frac{\partial h_1}{\partial x} = \frac{-\partial H/\partial x}{\partial H/\partial h}$, the above calculations establish that $\partial h_1/\partial\delta_{S|U} > 0$ and $\partial h_1/\partial\delta_{U|S} > 0$.

■

Proof of Propositions 8 and 9. Fix all parameters other than α. First note that, given other parameter values, the domain of α is limited by Assumptions 1, 3, and 5. We can calculate $\underline{\alpha}$ and $\bar{\alpha}$ as in the proof of Propositions 6 and 7.

$W^N > W^R$ if and only if

$$\delta_{S|U}(W_U^{SB} - W_U^{LF}) > (1-\delta_{U|S})W_S^{LF} + \delta_{U|S}\underline{W}_S^R - W_S^N \iff$$
$$\frac{\delta_{S|U}}{\alpha\bar{b}}\left[(\pi_U h - c)(\bar{b}\alpha - c_0 - c) - \frac{c}{2\alpha}(2c_0 + c - \alpha(c_0 + \pi_U h))\right]$$
$$> \frac{1}{2\bar{b}\alpha^2}\left[(2c_0 - 2\alpha(c_0+\pi_S h))(\pi_S\epsilon_{U|S}d^* - \pi_S\delta_{U|S}F_U^*) + (\pi_S\epsilon_{U|S}d^*)^2 - \delta_{U|S}(\pi_S F_U^*)^2\right] \iff$$
$$F(\alpha) \equiv 2\alpha^2\bar{b}\delta_{S|U}(\pi_U h - c) + \alpha[2\delta_{S|U}(c(c_0+\pi_U h)$$
$$-(\pi_U h - c)(c_0 + c)) + 2(c_0 + \pi_S h)\Delta_1] - \delta_{S|U}c(2c_0 + c) - 2c_0\Delta_1 - \Delta_2 > 0$$

where $\Delta_1 \equiv \pi_S\epsilon_{U|S}d^* - \pi_S\delta_{U|S}F_U^*$ and $\Delta_2 \equiv (\pi_S\epsilon_{U|S}d^*)^2 - \delta_{U|S}(\pi_S F_U^*)^2$. Note that, since $W_U^{SB} - W_U^{LF} > 0$ by Assumption 5, a necessary and sufficient condition for there to exist some $\alpha' \in (\underline{\alpha}, \bar{\alpha})$ such that $W^R > W^N$ is that

$$(2c_0 - 2\underline{\alpha}(c_0 + \pi_S h))\Delta_1 + \Delta_2 > 0 \tag{66}$$

If (66) does not hold, then set $\alpha_2^1 = \underline{\alpha}$. Otherwise, $F(\underline{\alpha}) < 0$ and $F(\cdot)$ is monotonically increasing in α. Thus, there either (i) exists some unique $\alpha' \in (\underline{\alpha}, \bar{\alpha})$ such that $F(\alpha) < 0$ for $\alpha < \alpha'$, $F(\alpha') = 0$, and $F(\alpha) > 0$ for $\alpha > \alpha'$ or (ii) $F(\alpha) < 0$ for all α'. If (i), then set $\alpha_2^1 = \alpha'$. Otherwise, set $\alpha_2^1 = \bar{\alpha}$.

$W^R > W^{LF}$ if and only if

$$(1-\delta_{S|U})(W_U^{SB} - W_U^{LF}) > \delta_{U|S}(W_S^{LF} - \underline{W}_S^R) \iff$$
$$\frac{(1-\delta_{S|U})}{2\alpha^2\bar{b}}[2\alpha(\pi_U h - c)(\bar{b}\alpha - c_0 - c) - c(2c_0 + c - 2\alpha(c_0 + \pi_U h))]$$
$$> \frac{\delta_{U|S}\pi_S F_U^*}{2\alpha^2\bar{b}}[2c_0 + \pi_S F_U^* - 2\alpha(c_0 + \pi_S h)] \iff$$
$$H(\alpha) \equiv 2\alpha^2\bar{b}(1-\delta_{S|U})(\pi_U h - c) +$$
$$\alpha[2\{\delta_{U|S}\pi_S F_U^*(c_0 + \pi_S h) + (1-\delta_{S|U})c(c_0+\pi_U h) - (1-\delta_{S|U})(\pi_U h - c)(c_0 + c)\}]$$
$$-c(1-\delta_{S|U})(2c_0 + c) - \delta_{U|S}\pi_S F_U^*(2c_0 + \pi_S F_U^*) > 0$$

$H(\underline{\alpha}) < 0$ and $H(\cdot)$ is monotonically increasing in α. Thus, there either (i) exists some unique $\alpha' \in (\underline{\alpha}, \bar{\alpha})$ such that $H(\alpha) < 0$ for $\alpha < \alpha'$, $H(\alpha') = 0$, and $H(\alpha) > 0$ for $\alpha > \alpha'$ or (ii) $H(\alpha) < 0$ for all α'. If (i), then set $\alpha_1^1 = \alpha'$. Otherwise, set $\alpha_1^1 = \bar{\alpha}$.

$W^N > W^{LF}$ if and only if

$$W_U^{SB} - W_U^{LF} > W_S^{LF} - W_S^N \iff$$
$$\frac{1}{2\alpha^2\bar{b}}[2\alpha(\pi_U h - c)(\bar{b}\alpha - c_0 - c) - c(2c_0 + c - 2\alpha(c_0 + \pi_U h))]$$
$$> \frac{\pi_S \epsilon_{U|S} d^*}{2\alpha^2\bar{b}}[2c_0 + \pi_S \epsilon_{U|S} d^* - 2\alpha(c_0 + \pi_S h)] \iff$$
$$J(\alpha) \equiv \alpha^2 2\bar{b}(\pi_U h - c) + 2\alpha[\pi_S \epsilon_{U|S} d^*(c_0 + \pi_S h) + c(2c_0 + c) - \pi_U h c_0]$$
$$-c(2c_0 + c) - \pi_S \epsilon_{U|S} d^*(2c_0 + \pi_S \epsilon_{U|S} d^*) > 0$$

$J(\underline{\alpha}) < 0$ and $J(\cdot)$ is monotonically increasing in α. Thus, there either (i) exists some unique $\alpha' \in (\underline{\alpha}, \bar{\alpha})$ such that $J(\alpha) < 0$ for $\alpha < \alpha'$, $J(\alpha') = 0$, and $J(\alpha) > 0$ for $\alpha > \alpha'$ or (ii) $J(\alpha) < 0$ for all α'. If (i), then set $\alpha_2^2 = \alpha'$. Otherwise, set $\alpha_2^2 = \bar{\alpha}$.

If $\alpha_1^1 < \min\{\alpha_2^1, \bar{\alpha}\}$ then let $\alpha_2 = \min\{\alpha_2^1, \bar{\alpha}\}$ and $\alpha_1 = \alpha_1^1$. Otherwise, let $\alpha_1 = \alpha_2 = \min\{\alpha_2^2, \bar{\alpha}\}$.

By construction, $\underline{\alpha} < \alpha_1 \leq \alpha_2 \leq \bar{\alpha}$ and, from the above analysis

1. Negligence is optimal for high values of α: $W^N > \max\{W^R, W^{LF}\}$ for $\alpha \in (\alpha_2, \overline{\alpha})$
2. Regulation is optimal for middle values of α: $W^R > \max\{W^N, W^{LF}\}$ for $\alpha \in (\alpha_1, \alpha_2)$
3. Laissez-faire is optimal for low values of α: $W^{LF} > \max\{W^R, W^N\}$ for $\alpha \in (\underline{\alpha}, \alpha_1)$

Now suppose parameter values are such that $\underline{\alpha} < \alpha_1 < \alpha_2 < \bar{\alpha}$. Then α_2 is defined by the equation

$$F(\cdot) \equiv 2\alpha^2\bar{b}\delta_{S|U}(\pi_U h - c) + \alpha[2\delta_{S|U}(c(c_0 + \pi_U h)$$
$$-(\pi_U h - c)(c_0 + c)) + 2(c_0 + \pi_S h)\Delta_1] - \delta_{S|U} c(2c_0 + c) - 2c_0\Delta_1 - \Delta_2 = 0$$

We have

$$\frac{\partial F}{\partial \alpha} = 4\alpha\bar{b}\delta_{S|U}(\pi_U h - c) + [2\delta_{S|U}(c^2 + c_0(2c - \pi_U h)) + 2(c_0 + \pi_S h)\Delta_1]$$
$$> 0 \text{ (by Assumption 5 and } \Delta_1 > 0)$$
$$\frac{\partial F}{\partial \delta_{S|U}} = 2\alpha^2\bar{b}(\pi_U h - c) + 2\alpha(c^2 + c_0(2c - \pi_U h)) - c(2c_0 + c)$$
$$> 0 \text{ (since } W_U^{SB} > W_U^{LF} \text{ by Assumption 5)}$$
$$\frac{\partial F}{\partial \delta_{U|S}} = \pi_S F_U^* \{\pi_S F_U^* + 2c_0 - 2(c_0 + \pi_S h)\alpha\}$$
$$> 0 \text{ (since } c_0 > \alpha(c_0 + \pi_S h) \text{ by Assumption 3)}$$
$$\frac{\partial F}{\partial \epsilon_{U|S}} = -\pi_S d^* [2\pi_S d^* \epsilon_{U|S} + 2c_0 - 2\alpha(c_0 + \pi_S h)]$$
$$< 0$$
$$\frac{\partial F}{\partial \epsilon_{S|U}} = -2\epsilon_{U|S}\pi_S \frac{\partial d^*}{\partial \epsilon_{S|U}}[c_0 + d^* - \alpha(c_0 + \pi_S h)]$$
$$< 0$$

Since $\frac{\partial \alpha_2}{\partial x} = \frac{-\partial F/\partial x}{\partial F/\partial \alpha}$, the above calculations establish that $\partial\alpha_2/\partial\delta_{S|U} < 0, \partial\alpha_2/\partial\delta_{U|S} < 0, \partial\alpha_2/\partial\epsilon_{U|S} > 0$, and $\partial\alpha_2/\partial\epsilon_{S|U} > 0$.

α_1 is defined by the equation

$$H(\cdot) \equiv 2\alpha^2\bar{b}(1 - \delta_{S|U})(\pi_U h - c)$$
$$+\alpha[2\{\delta_{U|S}\pi_S F_U^*(c_0 + \pi_S h) + (1 - \delta_{S|U})c(c_0 + \pi_U h) - (1 - \delta_{S|U})(\pi_U h - c)(c_0 + c)\}]$$
$$-c(1 - \delta_{S|U})(2c_0 + c) - \delta_{U|S}\pi_S F_U^*(2c_0 + \pi_S F_U^*) = 0$$

We have

$$
\begin{aligned}
\frac{\partial H}{\partial \alpha} &= 2\alpha\bar{b}(1-\delta_{S|U})(\pi_U h - c) + 2[(1-\delta_{S|U})(c^2 + c_0(2c - \pi_U h)) + \delta_{U|S}\pi_S F_U^*(c_0 + \pi_S h)] \\
&> 0 \text{ (by Assumption 5)} \\
\frac{\partial H}{\partial \delta_{S|U}} &= c(2c_0 + c) - 2\alpha[\alpha\bar{b}(\pi_U h - c) + c^2 + c_0(2c - \pi_U h)] \\
&< 0 \text{ (by Assumption 5)} \\
\frac{\partial H}{\partial \delta_{U|S}} &= \pi_S F_U^* \{2\alpha(c_0 + \pi_S h) - 2c_0 - \pi_S F_U^*\} \\
&< 0 \text{ (by Assumption 3)}
\end{aligned}
$$

Since $\frac{\partial \alpha_1}{\partial x} = \frac{-\partial H/\partial x}{\partial H/\partial \alpha}$, the above calculations establish that $\partial\alpha_1/\partial\delta_{S|U} > 0$ and $\partial\alpha_1/\partial\delta_{U|S} > 0$.

■

Proof of Lemma 2. To find the set of damage functions $d(\sigma_R, \sigma_J, \hat{p}) \geq 0$ that may be optimal, we consider the following maximization problem:

$$\max_{F(\cdot)\geq 0} W \tag{MB}$$

subject to

$$W = \underbrace{(1-\delta_{U|S})\int_{\frac{c_0+\pi_S[(1-\epsilon_{U|S})d(S,S,\hat{p}_{S|S})+\epsilon_{U|S}d(S,U,\hat{p}_{S|S})]+\hat{p}_{S|S}c}{\alpha}}^{\infty} b-(c_0+\hat{p}_{S|S}c+\pi_S h)dG(b)}_{\equiv W_{S|S}} \tag{67}$$

$$+\underbrace{\delta_{U|S}\int_{\frac{c_0+\pi_S\pi_S[(1-\epsilon_{U|S})d(U,S,\hat{p}_{U|S})+\epsilon_{U|S}d(U,U,\hat{p}_{U|S})]+\hat{p}_{U|S}c}{\alpha}}^{\infty} b-(c_0+\hat{p}_{U|S}c+\pi_S h)dG(b)}_{\equiv W_{U|S}}$$

$$+\underbrace{(1-\delta_{S|U})\int_{\frac{c_0+\pi_U(\hat{p}_{U|U})[(1-\epsilon_{S|U})d(U,U,\hat{p}_{U|U})+\epsilon_{S|U}d(U,S,\hat{p}_{U|U})]+\hat{p}_{U|U}c}{\alpha}}^{\infty} b-(c_0+\hat{p}_{U|U}c+\pi_U(\hat{p}_{U|U})h)dG(b)}_{\equiv W_{U|U}} \tag{68}$$

$$+\underbrace{\delta_{S|U}\int_{\frac{c_0+\pi_U(\hat{p}_{S|U})[(1-\epsilon_{S|U})d(S,U,\hat{p}_{S|U})+\epsilon_{S|U}d(S,S,\hat{p}_{S|U})]+\hat{p}_{S|U}c}{\alpha}}^{\infty} b-(c_0+\hat{p}_{S|U}c+\pi_U(\hat{p}_{S|U})h)dG(b)}_{\equiv W_{S|U}}$$

$$\hat{p}_{j|i} = \arg\max_{\hat{p}'_{j|i}} -(c\hat{p}'_{j|i}+\pi_i(\hat{p}'_{j|i})[(1-\epsilon_{-i|i})d(j,i,\hat{p}_{j|i})+\epsilon_{-i|i}d(j,-i,\hat{p}_{j|i})]) \tag{69}$$

for $i, j = S$ and U, $-S = U$ and $-U = S$.

Let $d^*(\cdot)$ denote a solution to (MB) and $\hat{p}^*_{j|i}$ denote the level of precaution taken by a type i firm classified as j under $d^*(\cdot)$. We now characterize $d^*(\cdot)$ through a series of claims.

Claim 11. *$\hat{p}^*_{j|S} = 0$ for $j \in \{S, U\}$.*

Proof. The proof is analagous to the proof of Claim 1. □

Claim 12. *Maximizing* (MB) *subject to the additional constraint that $\hat{p}_{j|U} = 0$ has a solution $d^*(\cdot)$ such that $d^*(j,S,0) = d^*(j,U,0) = 0$ for $j \in \{S,U\}$. If court and regulatory errors are positive then all solutions have this property.*

Proof. The proof is analagous to the proof of Claim 2. □

Claim 13. *Maximizing* (MB) *subject to the additional constraint that* $\hat{p}_{j|U} = 1$ *has a solution* $d^*(\cdot)$ *such that* $d^*(j, S, 0) = 0$ *and* $d^*(j, U, 0) = \frac{c}{(1-\epsilon_{S|U})\pi_U}$ *for* $j \in \{S, U\}$. *If court and regulatory errors are positive then all solutions have this property.*

Proof. The proof is closely related to the proof of Claim 3. □

Claim 14. *If* $\hat{p}^*_{U|U} = 0$ *then* $\hat{p}^*_{S|U} = 0$.

Proof. The proof is almost identical to the proof of Claim 8. □

Claim 15. *If* $d(\cdot)$ *is a solution to* (MB) *then so is* $d'(\cdot)$, *where* $d'(i, j, 0) = d(i, j, 0)$ *for all* $i, j \in \{S, U\}$ *and* $d'(i, j, 1) = 0$ *for all* $i, j \in \{S, U\}$.

Proof. The proof is similar to the proof of Claim 4. □

From Claims 11 - 15, we've established that there is always a solution to (MB) with $d(i, j, 1) = 0$ for all $i, j \in \{S, U\}$, $d(S, S, 0) = d(U, S, 0) = 0$ for all $i \in \{S, U\}$, and

$$(d(S, U, 0), d(U, U, 0)) \in \left\{(0, 0), \left(\frac{c}{(1-\epsilon_{S|U})\pi_U}, \frac{c}{(1-\epsilon_{S|U})\pi_U}\right), \left(0, \frac{c}{(1-\epsilon_{S|U})\pi_U}\right)\right\} \quad (70)$$

.

Moreover, if court and regulatory errors are positive then, for all $d^*(\cdot)$, $d^*(S, S, 0) = d^*(U, S, 0) = 0$ and

$$(d^*(S, U, 0), d^*(U, U, 0)) \in \left\{\underbrace{(0, 0)}_{\text{LF}}, \underbrace{\left(\frac{c}{(1-\epsilon_{S|U})\pi_U}, \frac{c}{(1-\epsilon_{S|U})\pi_U}\right)}_{\text{neg}}, \underbrace{\left(0, \frac{c}{(1-\epsilon_{S|U})\pi_U}\right)}_{\text{s-h neg}}\right\} \quad (71)$$

.

■

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