Markets, torts and social inefficiency

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We provide a model wherein oligopolists produce differentiated products that also have a safety attribute. Consumption of these products may lead to harm (to consumers and/or third parties), lawsuits, and compensation, either via settlement or trial. Firm-level costs reflect both safety investment and production activities, as well as liability-related costs. Compensation is incomplete, both because of inefficiencies in the bargaining process and (possibly) because of statutorily-established limits on awards. We compare the market equilibrium safety effort and output levels to what a planner who is able to set safety standards, but takes the market equilibrium output as given, would choose.

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1. Introduction

In this paper we examine the nexus between product markets and the legal system. We do this in the context of product safety, harm, and tort law. Firms' decisions regarding investment to improve product safety depend on both market-provided incentives and incentives provided by the tort system. Attributes of the market and of the technology that affect these decisions include the number of firms in the industry, the degree of substitutability between products, and the relationship between improved safety and production costs, as well as the relationship between improved safety and the likelihood and extent of harm. In particular, we show how the interplay of oligopolistic market structure and technological considerations alters results previously derived for monopolistic or perfectly competitive industries. Attributes of the tort system that affect safety effort decisions include the extent to which firms are held liable for the harms caused by their products, and the costs associated with litigation. In particular, we show how consideration of the extent and nature of externalities associated with third-party harms may further amplify, or ameliorate, losses arising due to the aforementioned oligopoly-generated inefficiencies.

We examine a model in which imperfectly competitive firms first choose safety effort, which affects both fixed and marginal costs, and then choose output levels.[1] We first consider a model in which only consumers can be harmed; moreover, compensation for harm is incomplete because of the possibility of settlement bargaining breakdown. We find that imperfectly competitive firms always provide too little output for any given level of safety effort. We examine two measures of product variety using a heterogeneous-goods oligopoly model: the number of firms, and the degree of substitutability of the products. Holding the degree of substitutability constant, an increase in the number of firms always reduces equilibrium safety effort. On the other hand, holding the number of firms constant, increasing the degree of substitutability first decreases, but ultimately increases, the equilibrium safety effort. An increase in a firm's safety effort has two effects: a "full-marginal-cost" effect (it lowers the firm's variable costs) and a "business-stealing" effect (it induces a reduction in rival firms' output). This business-stealing effect is an additional benefit to the firm from increasing its safety effort. The full-marginal-cost effect is decreasing, while the business-stealing effect is increasing, in the degree of substitution. Thus, when the products are poor substitutes, the return to safety effort (which reflects primarily the full-marginal-cost effect) is decreasing in the degree of substitution, but when the products are good substitutes, the return to safety effort (which now increasingly reflects the business-stealing effect) is increasing in the degree of substitution. This means that the equilibrium investment in safety is U-shaped in the degree of substitution, providing a number of results not encompassed by the current literature (summarized below) which emphasizes either monopolistic or perfectly competitive markets.

We compare equilibrium safety effort and output with a social benchmark embodied by a social planner who can choose safety effort, but is constrained to allow firms to make their own output decisions; thus, the planner takes the market equilibrium determination of output as given. This restricted social planner thereby specifies the socially optimal level of safety much as a social-welfare maximizing court system would, since courts involved in tort actions generally do not penalize firms for under-supply of output. In this case, we find that non-cooperative firms under-provide safety effort (relative to the restricted social planner's preferred level) when the products are relatively poor substitutes. However, when the products are sufficiently good substitutes, the non-cooperative firms will over-provide safety effort because they value business-stealing while society does not. Moreover, the more firms there are in the industry, the less substitutable their products need to be in order for the equilibrium to result in over-provision of safety effort.[2] This means that the market almost never provides the socially optimal level of safety when safety affects fixed costs (in contrast with the traditional argument, wherein safety only affects variable costs), and there is a broad set of conditions under which it over- or under-produces safety. Furthermore, by incorporating imperfect competition into the analysis we can see how product variety, and the intensity of strategic interaction, influence the efficiency of safety provision in the market.

Next, we add third-party victims to the model by assuming that consumption exposes a certain number of third parties per consumer to potential injury. Although consumer victims simply deduct anticipated uncompensated losses from their willingness to pay (thus forcing the firm to face the full marginal social costs), third-party victims have no such recourse. We find that the market with third-party victims behaves in a qualitatively similar way with respect to our two measures of product variety. Moreover, we find that equilibrium safety effort is increasing in the intensity of spillovers when (and only when) the firm's total liability costs for third-party harms are diminished by an increased safety effort. This occurs when the magnitude of the (pre-transaction) elasticity of market output with respect to safety effort is less than that of the (post-transaction) elasticity of the firm's per-unit third-party liability costs. When we compare the equilibrium safety effort with what would be chosen by our social planner, we find conditions under which greater (or lesser) substitutability is required to yield over-supply of safety effort in equilibrium. That is, we identify conditions under which the presence of third-party victims increases (or decreases) the set of parameters in which equilibrium safety effort will be inefficiently low. Interestingly, liability for third-party harms may lead to benefits for direct-product consumers; this occurs when such liability induces firms to improve safety. We also show that even when safety effort affects only variable costs, if third parties bear uncompensated losses then firms under-provide safety effort.

Finally, we delve into the settlement subgame that generates the respective losses borne by the firm and the injured parties. We consider how various policies, such as promoting alternative dispute resolution, imposing caps on damages awards, or increasing evidentiary standards affect the allocation of the cost of harm between the victim and the injurer, the extent of settlement, and the overall level of costs due to settlement failure. Alternative dispute resolution (such as arbitration or mediation) is viewed as a way of reducing the costs of adjudication, reserving the full-blown (and often very costly) trial process for relatively fewer cases. Although lowering the cost of adjudication reduces the likelihood of settlement, overall expected litigation costs are lower when the costs of adjudication are lower. Tort reform has been an on-going policy question of importance which, as of this writing, is heating up again. Many reformers argue for increased evidentiary standards (e.g., by shifting class actions from state to federal court), and caps on damages awards;

see, for example, VandeHei (2002), Ballard (2003), and Caher (2003). Both of these reforms reduce the plaintiff's expected recovery, and both promote settlement. Thus, these three policies all reduce the expected costs of the legal system. However, we find that changes in these policies that increase the expected costs of the legal system can, in some circumstances, have a beneficial effect upon social welfare. This occurs primarily when substantial third-party harms are externalized, resulting in insufficient safety investment and/or excessive output. In this case, additional legal costs can induce the firms to improve safety and/or reduce output. Our analysis also suggests forms of "tailored" tort reform that are likely to be preferable to those currently the subject of public discussion.

Relationship to literature

The topic of product quality has been addressed in both the industrial organization and law and economics literatures. The industrial organization literature considers quality provision in a market, where quality is the result of an effort level that affects both fixed and variable costs. In principle, quality can affect both demand and production cost in arbitrary ways. Spence (1975) shows that, for a given output level, a monopolist will over- (under-) provide quality if higher quality increases (decreases) the slope of the inverse demand curve. Spulber (1989) compares a monopolist to a social planner who chooses both quality (interpreted as safety) and output. Strict liability fully-insures consumers, and hence safety does not affect the demand curve. A monopolist provides the socially optimal level of safety effort for a given level of output; however, since the monopolist always produces too little output, the monopolist over- (under-) provides safety if an increase in safety increases (decreases) combined marginal production and liability costs.[3] This literature emphasizes the direct influence of quality on consumer demand, and abstracts from spillovers to third-parties, which are frequently important when the quality dimension is safety.

The standard law and economics analysis (Shavell, 1980, 2004) of the market provision of safety under strict liability assumes that safety effort involves a constant expenditure per unit of output and that harmed individuals are fully compensated.[4] In this case, the determination of safety effort is separable from that of output and, since the firm faces the social cost of harm, the firm is induced to choose the socially-optimal level of care. The market may be perfectly competitive (so output is also socially optimal) or imperfectly competitive (so output is under-supplied). Moreover, it is irrelevant whether the victims of harm are the firm's consumers or third parties.

In this paper, we generalize these two literatures to provide a more comprehensive model of how markets and the tort system interact to affect the equilibrium provision of output and safety. We generalize the industrial organization literature by considering a Cournot oligopoly in which firms produce horizontally-differentiated products which are (potentially) vertically-differentiated by a safety attribute as well. To our knowledge, such a Cournot oligopoly model with both horizontally- and vertically differentiated goods has not been considered to date.[5] Moreover, we assume that product failure results in harm to the consumer and (potentially) to third parties. For many products, the set of victims will consist of consumers alone, or a combination of consumers and third parties, as in cigarette smoking and automobile accidents. For others, the set of victims may consist only of third parties, whose harm is merely incidental to consumption, as in individuals who are harmed by a spill which occurs when gasoline is transported to its point of consumption.

Furthermore, we generalize the law and economics literature by considering incomplete compensation of victims and incorporating a significant, endogenously-determined, fixed-cost component of safety effort, as would arise when safety can be improved through investments (e.g., in R&D), such as in automobiles and pharmaceuticals. We assume that compensation is determined by the tort system, rather than by *ex ante* contracting between the firm and a consumer. In the case of injury, a firm cannot limit its liability for a consumer's harm through contractual means. On the other hand, under the penalty doctrine, the common law does not enforce stipulated damages in excess of expected damages (Rea, 1998, p. 24). Moreover, there is no possibility of contract with third parties. Thus, it is appropriate to treat compensation as the outcome of the legal process. Since the legal process sometimes involves asymmetric information and bargaining breakdown, compensation will be costly and incomplete. Although consumers have the ability to shift these costs back to the firms via the product's price, third parties have no such opportunity.

A further contrast with the law and economics literature is that we consider imperfectly competitive market structures and show that this too affects the predictions of the analysis. This occurs because when safety effort affects fixed costs, output and safety effort decisions are not separable. We show how the number of firms and the degree of product substitutability influence both the market provision, as well as the socially efficient levels, of safety and output.

Plan of the paper

Section 2 provides the basic elements of our model, including safety effort investment, manufacturing costs and liability-related losses for the firm. We also specify a model of consumer choice which incorporates the consumer's utility for the product and for product variety, and their disutility for uncompensated harms they may bear. Section 3 analyzes a product-differentiated oligopoly in which firms first choose safety effort levels and then choose output levels. In this section, we focus on the two-party case, wherein the victims of harm are the product's consumers. Section 4 considers the restricted social planner's optimal level of safety and compares this with what would obtain in the market equilibrium. Section 5 extends our analysis to include third-party harms. Section 6 expands the analysis by tracing the effects of potential changes in tort law on market incentives. Section 7 summarizes our results and discusses their implications. An Appendix and a Web Appendix[6] provide technical details and supplementary materials.

2. Model setup, structure and notation

Preliminaries: firms, consumers and the social planner

Consider an industry comprised of n firms, with each firm producing a (possibly differentiated) product. Differentiation here will be in terms of safety and some other (parametrically fixed) attribute to be discussed in greater detail below. N identical consumers buy these products and some consumers suffer harms; the degree of harm can be different for each consumer and is their private information. Assuming firms are strictly liable for the harm they cause, those consumers who are harmed bring suit seeking compensation.[7] We assume that suits are costless to file and to negotiate, but resorting to trial is costly. We follow the American rule and assume that each party pays their own trial costs if trial occurs. At trial a court perfectly discerns the true level of harm suffered and awards damages based on this harm. Pretrial settlement negotiations involve either the consumer (as the plaintiff, P, facing court costs k_P) or the firm (as the defendant, D, facing court costs k_D) proposing a settlement amount, which the other party can either accept or reject. Acceptance of a proposed settlement offer results in the appropriate cash transfer, while rejection leads immediately to trial.

Before production, firm i chooses a level of safety effort, x_i, generating a cost of tx_i, where $t \geq 0$ is a parameter representing the unit cost of safety effort. Then, upon observing each firm's choice of effort level, all firms simultaneously choose their respective levels of output. We view this timing as plausible because when safety effort affects the fixed cost of production, it is a more durable attribute than output. For instance, suppose that safety effort involves investment in R&D to develop a safer product, or the design of a production facility (e.g., a food processing facility) to produce a safer product. This investment is plausibly viewed as occurring on a less frequent basis than output choice. If safety effort only affected variable costs (e.g., safer products simply require more expensive inputs), then a simultaneous choice of safety effort and output would be an alternative plausible game form.

Assume that firm i produces output under conditions of constant marginal cost $m(x_i)$ and denote firm i's output per consumer as q_i; therefore total output for firm i is Nq_i. Thus, all firms face the same unit production cost function $m(\bullet)$; we assume[8] that $m_x(\bullet) > 0$, and that $m_{xx}(\bullet) \geq 0$; that is, safer products are more costly to produce and further improving the safety of a product becomes increasingly costly. Safety effort influences, but does not determine, the likelihood of a consumer being harmed by firm i's product (i.e., the likelihood of an accident occurring), denoted as θ_i. To capture this influence, we assume that θ_i is distributed according to $F(\theta; x_i)$. If an accident occurs, then the monetary value of damages suffered is denoted as δ_i, which we assume is distributed according to $G(\delta; x_i)$. All firms face the same distribution functions F and G, except as influenced by their individual choices of safety effort x. Moreover, we assume that F and G satisfy conditions for first-order stochastic dominance (FOSD): $x' > x$ implies that: i) $F(\bullet; x)$ first-order stochastically dominates $F(\bullet; x')$; and ii) $G(\bullet; x)$ first-order stochastically dominates $G(\bullet; x')$. Thus, for instance, one implication is that increases in the safety effort level result in a reduction in *ex ante* expected damages. We further assume that F (respectively, G) is continuous and differentiable, with density f (respectively, g). We also assume that the densities are strictly positive on their supports (which are taken to be non-degenerate intervals). Moreover, the lower end-points of the supports, denoted $\underline{\theta}$ for F and $\underline{\delta}$ for G, are such that $\underline{\theta} > 0$ and $\underline{\delta} > k_P$ and either or both are (possibly) functions of x. This means that perfect safety is not possible (θ cannot be zero, no matter how large x is) and that any consumer who is harmed has a credible threat of proceeding to trial.

We focus on the case of strict liability in tort: if firm i's product has harmed a consumer, the firm is liable for the damages suffered (but not the consumer's court costs, if incurred).[9] Let $L_D(\delta; x)$ be the costs from settlement bargaining and possible litigation for a firm that exerted safety effort x and faces a consumer with damages δ; thus, the expected value of $L_D(\delta; x)$, denoted $EL_D(x)$, is $\int L_D(\delta; x)g(\delta; x)\mathrm{d}\delta$. Therefore, firm i's expected cost of liability (per unit produced) is $v(x_i) \equiv \hat{\theta}(x_i)EL_D(x_i)$, where $\hat{\theta}(x_i) \equiv \int \theta f(\theta; x_i)\mathrm{d}\theta$ is the *ex ante* expected probability of an accident. In general, we expect that $v_x(\bullet) < 0$, and $v_{xx}(\bullet) > 0$. We provide an example of a settlement subgame in the Appendix with these properties.

Each consumer derives utility from consuming the n goods in question as well as a numeraire good, and has a quasilinear utility function, $U(q_1, ..., q_n) + q_{n+1}$, where good $n + 1$ is the numeraire good (i.e., it represents a composite of all other goods purchased by the consumer), with its price equal to 1. In particular, we assume that U is quadratic in form, with parameters $\alpha > 0$, $\beta > 0$, and γ:

$$U(q_1, ..., q_n) = \sum_i \alpha q_i - ½(\sum_i \beta q_{\mathrm{i}}^2 + \sum_i \sum_{j \neq i} \gamma q_i q_j),$$

where γ is the degree of product substitution between any two products in the class of interest.[10] We take γ to lie in the interval $[0, \beta)$, with perfect substitutes being the limit case when $\gamma \to \beta$. Note that if $\gamma = 0$, then each product is independent of each other product, and each firm has a monopoly in its product market. Thus, in the monopoly case we consider below, we take $n = 1$and let $U(q) = \alpha q - \beta q^2/2$, while for the oligopoly case, if the n firms produce a homogeneous good (that is, the limit case for $\gamma \to \beta$), then $U(q_1, ..., q_n) = \sum_i(\alpha q_{\mathrm{i}} - \beta \sum_j q_i q_j/2)$.

This utility function implies that the consumer likes variety. In equilibrium, the consumer will purchase some of each good. Moreover, the more varieties there are (i.e., the larger is n), or the more different the varieties are (i.e., the smaller is γ), the greater is the total quantity of goods in this class that the consumer will purchase: each variety competes for the consumer's budget not only against other varieties of the same good, but against the numeraire good (i.e., all other goods) as well. Thus, if restaurant meals are the good in question, more variety in the restaurants available will result in greater consumption of restaurant meals overall, at the expense of all other goods.

Restaurant meals are also a class of products that are imperfect substitutes with safety attributes (x). Food storage and preparation equipment must be chosen and installed, food inspection and preparation protocols must be designed, and workers must be instructed in these protocols and monitored. These constitute investments (independent of output) that affect product safety, as they affect the likelihood that food will become contaminated by organisms such as *salmonella*, *e. coli*, *listeria*, and *Hepatitis A*. This contamination, in turn, may result in a consumer becoming ill, with the extent of injury (varying from mild stomach ache to death) also affected by investment in safety.

Other examples of products that are imperfect substitutes with safety attributes include toys, various drugs such as pain relievers and prescription antibiotics, household cleaners, and modes of transportation. Furthermore, although we will construct the demand curve for the products in the class of interest from the utility function of a representative consumer who prefers variety, one could alternatively simply assume a linear inverse demand curve for product i which arises from aggregating demands from consumers with diverse preferences. In this case, individual consumers need not demand some of each variety, so the model can be applied to differentiated-products markets such as those for automobiles, cigarettes and pharmaceuticals.

Consumers are rational and anticipate the effect of safety effort by each firm on the likelihood of harm as well as the likely level of damages they will suffer.[11] As potential plaintiffs they know that if their realized damages are δ, then incorporating settlement bargaining and possible litigation implies that their uncompensated losses will amount to $L_P(\delta; x)$. Therefore, consumers considering a purchase of good i recognize that they face a stochastic loss of $\theta_i L_P(\delta_i; x_i)$ per unit. Thus, our model of the consumer is to choose $(q_1, ..., q_n)$ so as to maximize their expected utility of consumption net of the expenditure on the n goods (the consumption of all other goods is found as the residual):

$$\max E_{\theta\delta}\{U(q_1, ..., q_n) + I - \textstyle\sum_i [p_i + \theta_i L_P(\delta_i; x_i)]q_i\},$$

where I is the consumer's income. Denote the expected loss for any given x (given an accident has occurred) as $EL_P(x) \equiv \int L_P(\delta; x)g(\delta; x)d\delta$. This loss is the expected harm (given an accident), $\hat{\delta}(x) \equiv \int \delta g(\delta; x)d\delta$, minus any transfer from the defendant due to settlement or trial, plus any court costs incurred. Thus, the consumer's choice problem can be replaced by:

$$\max U(q_1, ..., q_n) + I - \textstyle\sum_i [p_i + u(x_i)]q_i,$$

where $u(x_i) \equiv \hat{\theta}(x_i)EL_P(x_i)$. Note that we expect that $u_x(\bullet) < 0$, but that $u_{xx}(\bullet) > 0$. Again, as with $v(\bullet)$, we provide an example of a settlement subgame in the Appendix that exhibits these properties. Thus, for positive demands, the inverse demand function in our general case for product i is:

$$p_i(x_i, q_1, ..., q_n) = \alpha - u(x_i) - \beta q_i - \gamma \textstyle\sum_{j \neq i} q_j,$$

with the obvious simplifications for the monopoly and homogeneous oligopoly cases.

For any level of safety effort x, $u(x) + v(x)$ is equal to the *ex ante* expected harm plus any inefficiencies that arise from failed bargaining (i.e., expected trial costs); transfers from D to P wash out of this sum. Expected trial cost, conditional on an accident occurring, is the product of the trial costs that would be incurred by P and D should trial occur ($K \equiv k_P + k_D$) times the likelihood of trial; denote the expected trial cost as $ETC(x)$. We assume that $ETC_x(\bullet) < 0$ and $ETC_{xx}(\bullet) > 0$; in the Appendix we provide an example of a settlement game in which these assumptions hold.

In summary, we assume that n, N, x_i, t, q_i, F, G, $m(x)$, $U(q_1, ..., q_n)$, the game form for the settlement bargaining model, k_P and k_D are (or become, in the case of simultaneously chosen variables) common knowledge, and we also assume that no consumer can "fake" being harmed. There are two avenues along which firms may be differentiated, namely through x and γ. Moreover, there are three avenues along which competition among firms can be increased, namely through increases in x, n and γ. We shall take n and γ as exogenously-specified parameters, and x as endogenously determined. Competition itself will be captured by assuming that firms compete non-cooperatively first by choosing safety effort levels; then, given knowledge of all firms' choices of these levels, they non-cooperatively choose output levels (price strategies are considered at the end of Section 4). Equilibrium levels of safety effort and output for firm i in an n-firm oligopoly will be denoted x_i^n and q_i^n, respectively; in the monopoly case we will denote the optimal choices of these variables as x^1 and q^1, respectively.

Finally, we will consider a restricted social planner (*RSP*) who can set the level of safety effort, but cannot control either the level of output or the number of firms. *RSP*'s optimal safety effort level will be denoted X^{nq} and this will imply a (per customer) equilibrium level of output Q^{nq}. Thus, capital letters remind the reader that the variables are determined by the planner while superscripts remind the reader about which variables are taken as given (uncontrolled) by the planner.

Social and private safety and production costs

The sum $u(x) + v(x) = \hat{\theta}(x)[EL_P(x) + EL_D(x)] = \hat{\theta}(x)[\hat{\delta}(x) + ETC(x)]$ provides the *ex ante* expected post-production (per unit) costs given safety effort x; adding $m(x)$ yields the "full marginal cost" per unit of output produced: $FMC(x) \equiv m(x) + u(x) + v(x)$. This function plays a central role in the results to be developed below, so we wish to take a few moments to discuss it.[12]

Assumption 1. i) $m(\bullet)$, $u(\bullet)$, $v(\bullet)$ are twice continuously differentiable;

ii) $m(\bullet) > 0$, $m_x(\bullet) > 0$, $m_{xx}(\bullet) \geq 0$; $u(\bullet) > 0$, $u_x(\bullet) < 0$, $u_{xx}(\bullet) > 0$, $v(\bullet) > 0$, $v_x(\bullet) < 0$, $v_{xx}(\bullet) > 0$;

iii) $\alpha - FMC(0) > 0$; $FMC_x(0) < 0$; $\lim_{y\to\infty} FMC_x(y) > 0$.

Assumption 1 provides conditions that ensure that *FMC* is strictly convex and "U-shaped" and that the product in question is socially valuable even if there were no safety effort. Thus, there exists $\bar{x} > 0$ such that $FMC_x(\bar{x}) = 0$; this is the level of safety effort that appears in the traditional law and economics literature. In the sequel we further assume that all derivatives of *FMC* (with respect to x and any parameters) are bounded for $x \in [0, \bar{x}]$.

3. Market provision of safety and output: the two-party case

Profits for firm i for safety effort level x_i and the vector of firm outputs $(q_1, ..., q_n)$ are:

$$\pi_i(x_i, q_1, ..., q_n) \equiv p_i(x_i, q_1, ..., q_n)Nq_i - m(x_i)Nq_i - tx_i - v(x_i)Nq_i.$$

The first term on the right is the firm's revenue at the market price. The second and third terms are variable production costs and safety effort costs, while the fourth term is the expected liability costs.[13] Substitution of elements from the previous section allows us to write firm i's profit as:

$$\pi_i(x_i, q_1, ..., q_n) = Nq_i[\alpha - \beta q_i - \gamma \textstyle\sum_{j\neq i} q_j - FMC(x_i)] - tx_i.$$

Note that it is immediate from the profit function that the firm faces the full marginal cost associated with the provision of the product; this is because consumers discount the value of the product by the likely costs that will be imposed due to an accident.[14] In what follows we always assume that the profit function for firm i is strictly concave in (x_i, q_i). Moreover, since effort levels are chosen prior to outputs, the subgame-perfect equilibrium output levels will be functions of the safety effort levels and therefore we will maintain the following assumption.

Assumption 2. The reduced-form profit function for firm i (as a function of the vector of safety effort levels) is strictly concave (with negative second derivative) in its own safety effort level, x_i, for $i = 1,..., n$. Moreover, assume that equilibria at each stage are interior and equilibrium profits are non-negative.

Monopoly provision

If there is only one firm in the industry, then we can write the firm's profits as $\pi(x,q) = Nq[\alpha - \beta q - FMC(x)] - tx$. Maximizing with respect to output yields the monopoly output $q^1(x) = (\alpha - FMC(x))/2\beta$. Substituting into $\pi(x,q)$ yields the reduced-form profit function $\tilde{\pi}(x) \equiv N(\alpha - FMC(x))^2/4\beta - tx$. Maximizing $\tilde{\pi}(x)$ yields the following first-order condition for the firm's optimal safety effort, denoted x^1:

$$-Nq^1 FMC_x(x^1) - t = 0. \tag{1}$$

Moreover, let:

$$H(x;\, a) \equiv -(\alpha - FMC(x))FMC_x(x) - a. \tag{2}$$

An immediate implication of Assumption 2 is that $H_x < 0$ for all x. Substitution of $q^1(x)$ into equation (1) and simplification implies that equation (1) can be re-written as $H(x^1;\, a^1) = 0$, where $a^1 \equiv 2\beta t/N$. Assuming that $H(0;\, a^1) > 0$, and noting that $H(\bar{x};\, a^1) < 0$, it follows from $H_x < 0$ that there exists a unique solution $x^1 \in (0, \bar{x})$. Thus, the profit-maximizing amount of safety effort is less than that which minimizes $FMC(x)$.

We make this observation because standard theory in law and economics (see, for example, Shavell, 2004, or Cooter and Ulen, 2004) implies that, under strict liability, firms will choose the level of care that minimizes per unit precaution costs plus per unit expected losses from harm, $FMC(x)$; that is, $x = \bar{x}$. Obviously this doesn't hold here because we have included an endogenously-determined level of fixed costs (tx) as part of the firm's cost function, while the aforementioned literature has focused on the case wherein safety investment only affects variable costs.[15]

Note also that, since $H_x < 0$, one can readily show that $dx^1/dt < 0$, $dx^1/d\beta < 0$, $dx^1/d\alpha > 0$, and dx^1/dN

> 0. In other words, more costly safety effort (i.e., increased t) and lower individual marginal willingness to pay (i.e., increased β) both result in reductions in the level of safety effort chosen by the firm, while an increase in the aggregate number of consumers (or the choke price) results in an increase in the level of safety effort chosen.

Finally, as an alternative interpretation, using the fact the $FMC(x) \equiv m(x) + u(x) + v(x)$, we can re-write equation (1) as:

$$-Nq^1 u_x(x^1) = t + Nq^1(m_x(x^1) + v_x(x^1)). \tag{3}$$

Since $u_x < 0$, the left-hand-side is positive. This is the effect on revenue brought about by an increase in x. Because increasing x reduces the consumer's expected loss from harm, this increase affects their willingness to pay. On the right-hand-side of equation (3) is the impact on items which are purely cost effects: the direct safety effort cost, tx^1, production costs, $Nq_1 m(x^1)$, and direct expected liability costs, $Nq_1 v(x^1)$. Thus, equation (3) provides the familiar balancing of marginal revenue and the firm's marginal cost (due to adjustment of the safety level).

Oligopoly provision

If there are n firms in the industry, firm i's profit function is as shown earlier:

$$\pi_i(x_i, q_1, ..., q_n) = Nq_i[\alpha - \beta q_i - \gamma \textstyle\sum_{j\neq i} q_j - FMC(x_i)] - tx_i.$$

As indicated at the beginning of Section 2, we assume that all n firms (simultaneously and non-cooperatively) choose individual levels of safety effort, x_i, $i = 1, ..., n$, which then become common knowledge for all, and then the n firms (simultaneously and non-cooperatively) choose their output levels, q_i, $i = 1, ..., n$. Thus, finding the Cournot equilibrium for the output level stage conditional on the vector of safety efforts, the first-order condition for firm i's choice of q_i is:

$$\alpha - 2\beta q_i - \gamma\sum_{j\neq i}q_j - FMC(x_i) = 0. \tag{4}$$

Solving for the equilibrium (per consumer) quantities, we obtain:

$$q_i^n = [(2\beta - \gamma)\alpha - (2\beta + (n\text{-}2)\gamma)FMC(x_i) + \gamma\sum_{j\neq i}FMC(x_j)]/[(2\beta - \gamma)(2\beta + (n\text{-}1)\gamma)].$$

Substituting this equilibrium output level (which is a function of the n safety levels, suppressed so as to simplify exposition) into the profit function for firm i, the first-order condition for firm i for choosing x_i (given any conjectured vector of choices of safety levels for the other n firms) can be written as:

$$\{- Nq_i^n FMC_x(x_i) - t\} + \{Nq_i^n\gamma\sum_{j\neq i}[- \partial q_j^n/\partial x_i]\} = 0. \tag{5}$$

Note that the first term in braces is similar to (1), the first-order-condition for safety effort for a monopolist; it differs by the fact that the quantity, q_i^n, is for an oligopolist, not a monopolist. By construction, this is the marginal effect on i's profit that is directly associated with increasing safety effort; we refer to this term as the "full-marginal-cost" effect of safety effort on profit, since increases in safety effort both reduce the firm's costs and increase the consumer's willingness to pay. The term in the second set of braces is absent from (1); this term reflects the effect of an increase in x_i on the equilibrium output levels for all the other firms in the industry. Recalling the first-order condition for q_i^n (i.e., equation (4)), it is clear that $[- \partial q_j^n/\partial x_i] = -\gamma FMC_x(x_i)/[(2\beta - \gamma)(2\beta + (n\text{-}1)\gamma)] > 0$, so that the term in the second set of braces is positive. This "business-stealing" effect on marginal profits is a consequence of the presence of the other firms: if firm i increases x_i, rival firms decrease their equilibrium output levels, shifting demand in the direction of firm *i*.[16]

Symmetric safety effort in oligopoly equilibrium

If we let $x^n \equiv x_1^n = x_2^n = ... = x_n^n$, then the subgame-perfect equilibrium quantities (upon substitution) are:

$$q^n(x^n) = (\alpha - FMC(x^n))/(2\beta + (n\text{-}1)\gamma), \tag{6}$$

and the equilibrium x^n is given implicitly by:[17]

$$- Nq^n(x^n)FMC_x(x^n)\{1 + \gamma^2(n\text{-}1)/[(2\beta - \gamma)(2\beta + (n\text{-}1)\gamma)]\} - t = 0. \tag{7}$$

Let $a^n \equiv (t/N)(2\beta - \gamma)(2\beta + (n\text{-}1)\gamma)^2/[(2\beta - \gamma)(2\beta + (n\text{-}1)\gamma) + \gamma^2(n\text{-}1)]$; then (7) can be re-written as $H(x^n; a^n) = 0$. Since $\mathrm{d}x^n/\mathrm{d}a^n = 1/H_x$ and $H_x < 0$, one can readily show that: $\mathrm{d}x^n/\mathrm{d}t < 0$, $\mathrm{d}x^n/\mathrm{d}N > 0$, $\mathrm{d}x^n/\mathrm{d}\beta < 0$, $\mathrm{d}x^n/\mathrm{d}\alpha > 0$, and $\mathrm{d}x^n/\mathrm{d}n < 0$. The first four effects are the same (in sign) as in the monopoly case; that is, more costly safety effort (i.e., increased *t*) and lower individual marginal willingness to pay (i.e., increased β) both result in reductions in the level of safety effort chosen by the firm, while an increase in the aggregate number of consumers (or the choke price) results in an increase in the level of safety effort chosen. The fifth effect arises due to the presence of other firms; the greater the variety (measured by the number of firms, *n*) the lower will be the market share of each firm and the lower will be the equilibrium safety effort taken by any single firm.

Another effect that arises due to the presence of other firms concerns exogenous changes in γ, a different measure of variety. The effect of γ on x^n is first negative, but eventually positive: there exists a $\gamma^{min}(\beta, n) \in (0, \beta)$ such that $\mathrm{d}x^n/\mathrm{d}\gamma \gtrless 0$ as $\gamma \gtrless \gamma^{min}(\beta, n)$.[18] Figure 1 illustrates the effect of γ and *n* on x^n (note that we have illustrated this effect as convex; in fact we only know the curves to be first declining and then rising). Note that when $n = 1$ or (for all n) when $\gamma = 0$, the equilibrium safety effort is that provided by the monopolist (x^1), which is shown on the left axis, as is the value $\bar{x}$, the level of safety effort that minimizes $FMC(x)$. Thereafter, x^n initially declines as γ increases, reaches a minimum at $\gamma^{min}(\beta, n)$, and then increases as γ continues to increase (but is always less than x^1). It is straightforward to show that $\partial\gamma^{min}(\beta, n)/\partial n > 0$ and that $\lim_{n\to\infty}\gamma^{min}(\beta, n) = \beta$.

Place Figure 1 about here

Thus, our two ways of thinking about changes in variety have both positively- and negatively-correlated effects on the equilibrium safety level. Initially, as either n or γ increases from the monopoly setting, competition (from another product or a better substitute) drives output (and, hence, the marginal return to safety effort) down. However, once γ becomes large enough (above γ^{min}), increases in the substitutability of the products actually leads to increases in the equilibrium safety level. This is due to the two previously-mentioned effects of safety effort: the full-marginal-cost effect (which is decreasing in the degree of substitution) and the business-stealing effect (which is increasing in the degree of substitution). Thus, when the products are poor substitutes, the return to safety effort (which reflects primarily the full-marginal-cost effect) is decreasing in the degree of substitution, but when the products are good substitutes, the return to safety effort (which now increasingly reflects the business-stealing effect) is increasing in the degree of substitution. Finally, it can be shown that $dq^n/dN > 0$, $dq^n/dn < 0$, $dq^n/dt < 0$, $dq^n/d\beta < 0$, $dq^n/d\alpha > 0$, and $dq^n/d\gamma < 0$ when $\gamma \leq \gamma^{min}$ (and ambiguous otherwise). Notice that both equilibrium q^n and equilibrium x^n are increasing in N. Consumers exert a positive externality on one-another: more consumers results in higher safety effort, lower full marginal costs and higher equilibrium quantities per consumer.

For convenience, we summarize the symmetric equilibrium in Proposition 1 below.

Proposition 1. In the n-firm symmetric safety effort equilibrium (with no third parties)

i) per customer output for each firm, $q^n(x^n)$, is given by equation (6) and is increasing in N and α, and decreasing in t, β, n, and γ (for $\gamma \leq \gamma^{min}$);

ii) safety effort at each firm, x^n, is defined (implicitly) by equation (7) and is increasing in N, α and γ (for $\gamma > \gamma^{min}$), and decreasing in t, β, n, and γ (for $\gamma < \gamma^{min}$);

iii) $\partial\gamma^{min}(\beta, n)/\partial n > 0$ and $\lim_{n \to \infty}\gamma^{min}(\beta, n) = \beta$.

4. Socially optimal provision of safety and output: the two-party case

We now consider the socially optimal level of safety effort and output. We formulate the problem faced by *RSP*, who chooses the level of safety, taking the firms' non-cooperative equilibrium choices for output (conditional on safety level) as given. *RSP* maximizes social welfare, allowing for n firms and maintaining strict liability for harm. Thus, *RSP*'s problem is:

$$\max_X \{NU(Q_1, ..., Q_n) - \textstyle\sum_i[NQ_iFMC(X_i) + tX_i] \mid Q_i = q^n(X_1, ..., X_n), i = 1, ..., n\}. \tag{8}$$

In what follows we restrict attention to the symmetric solution; let (X^{nq}, Q^{nq}) solve *RSP*'s problem. The first-order conditions yield the following equations for the *RSP* quantity and safety effort level:

$$Q^{nq} = (\alpha - FMC(X^{nq}))/(2\beta + (n\text{-}1)\gamma); \tag{9}$$

$$-NQ^n(X^{nq})FMC_x(X^{nq})\{(3\beta + (n\text{-}1)\gamma)/(2\beta + (n\text{-}1)\gamma)\} - t = 0. \tag{10}$$

That is, $H(X^{nq}; A^{nq}) = 0$, where $A^{nq} \equiv (t/N)(2\beta + (n\text{-}1)\gamma)^2/(3\beta + (n\text{-}1)\gamma)$. Since A^{nq} is monotonically increasing in γ and in n, X^{nq} is monotonically decreasing in γ and in n (for $\gamma > 0$). Moreover, from the definition of A^{nq} it is evident that X^{nq} is increasing in N (and α) and decreasing in t and β.

By definition, for any fixed level of safety effort, $Q^{nq}(x) = q^n(x)$. Thus, the (restricted) socially optimal, and the equilibrium, output levels are different only to the degree that the socially optimal, and equilibrium, safety effort levels are different: $q^n(x^n) \gtrless Q^{nq}(X^{nq})$ as $x^n \gtrless X^{nq}$. Since $H_x < 0$, then $x^n \gtrless X^{nq}$ if and only if $\gamma \gtrless \Gamma^{nq}(\beta, n)$, where $\Gamma^{nq}(\beta, n)$ equates A^{nq} to a^n. $\Gamma^{nq}(\beta, n)$ provides the value of γ wherein the function describing X^{nq} crosses that for x^n; at this point, the equilibrium safety effort produced by the n-firm oligopoly is the same as the restricted social planner would have chosen. When $n = 2$, this critical value of γ is on the boundary (i.e., $\Gamma^{nq}(\beta, 2) = \beta$); as the number of firms grows, the two curves cross in the interior of $[0, \beta]$.[19] Thus, when $n > 2$, then $\Gamma^{nq}(\beta, n) < \beta$, so that there is a set of γ-values such that the n-firm oligopoly over-supplies safety. Also, since $\partial\Gamma^{nq}(\beta, n)/\partial n < 0$, the set of γ-values wherein x^n exceeds X^{nq} increases as n increases: with more firms, progressively weaker degrees of product substitution still result in a market equilibrium level of safety effort that is in excess of the *RSP* socially optimal level.

Our results are illustrated in Figure 2; note that, while illustrated as convex, the solid curve for X^{nq} need not be convex, just monotonically decreasing. We summarize the analysis of *RSP*, and the comparisons with the market equilibrium outcomes, in Proposition 2.

Place Figure 2 about here

Proposition 2. For the restricted social planer:

i) per customer output for each firm, $Q^n(X^{nq})$, is given by equation (9), and is increasing in N and α, and decreasing in t, β, γ, and n (for $\gamma > 0$);

ii) safety effort for each firm, X^{nq}, is given by equation (10), and is increasing in N and α and decreasing in t, β, γ, and n (for $\gamma > 0$);

iii) safety effort and output level are lower in market equilibrium than if chosen by *RSP* if and only if $\gamma < \Gamma^{nq}(\beta, n)$;

iv) $\Gamma^{nq}(\beta, 2) = \beta$, $\Gamma^{nq}(\beta, n) \in (0, \beta)$ for all $n > 2$ and $\partial\Gamma^{nq}(\beta, n)/\partial n < 0$.

Social and market implications of assuming price competition for the market subgame

Finally, one might consider using price strategies in the market subgame. The overall equilibrium is well-behaved if products are relatively poor substitutes but, since higher safety effort by firm *i* causes its rivals to lower their prices, and since prices are strategic complements, the firm now faces an additional cost associated with higher safety effort. Thus, under-provision of safety effort may be even more likely when firms compete in price strategies. Moreover, overall equilibrium requires mixed strategies (in safety effort) when the products are sufficiently close substitutes (see the Web Appendix for a fuller discussion of the use of price strategies).

5. Market equilibrium and social optimality in the three-party case

Preliminaries: model modifications

We now extend our analysis to consider safety effort and output choice when use of a product by consumers of a firm leads to harms suffered by non-consumers. We again focus on the symmetric solution (in safety effort and quantities) and we assume that bilateral precaution (in particular, by each firm's consumers) is not possible. Thus, for example, in the well-known Pinto case (see Viscusi, 1991), owners of Pintos, and of cars that had collisions with them, were harmed due to a design flaw (placement of the gas tank) rather than due to the owner's poor driving. As an alternative example, in Daughety and Reinganum (2002), we discussed lawsuits against Conoco for leakage of gasoline from their gas station storage tanks into water tables near approximately fifty communities nationwide. In that case, customers of the gas station were not harmed, but local residents (who need not be customers) were affected by the ongoing operation of the gas stations; moreover, there were no precautions consumers of gasoline could have taken to lessen the harm to non-consumers.

To formalize this, we again assume there are N consumers of the products provided by the n firms, but now assume that each consumer's per-unit consumption of the product exposes ϕ others to the risk of harm; that is, let $\phi \geq 0$ be the (exogenously-determined) exposure rate, or "technology" of spillover of harms to non-consumers from consumers. Then the number of non-consumers of firm i's product that are at risk is $\phi N q_i$. Let the expected per-unit loss for a non-consumer associated with harms from firm i's product be denoted $\tilde{u}(x_i)$, and assume that $\tilde{u}_x(\bullet) < 0$ and $\tilde{u}_{xx}(\bullet) > 0$, in correspondence to our earlier assumptions on $u(\bullet)$. Similarly, let $\tilde{v}(x_i)$ be firm i's expected per-unit cost arising from liability for harms to a non-consumer, with $\tilde{v}_x(\bullet) < 0$ and $\tilde{v}_{xx}(\bullet) > 0$. Let the full marginal costs per unit faced by the firm be $FMC^f(x_i) \equiv FMC(x_i) + \phi\tilde{v}(x_i)$.

Note that social per-unit costs, $FMC^S(x_i) \equiv FMC(x_i) + \phi(\tilde{u}(x_i) + \tilde{v}(x_i)) = FMC^f(x_i) + \phi\tilde{u}(x_i)$, reflect production costs plus expected harms suffered by consumers and by non-consumers, as well as losses the litigants face due to any inefficiencies in the settlement and litigation subgame. Therefore, if $\phi = 0$, then $FMC^S(x) = FMC^f(x) = FMC(x)$, while if $\phi > 0$, then $FMC^S(x) > FMC^f(x) > FMC(x)$. In particular, let $\bar{x}^f$ be such that $FMC^f_x(\bar{x}^f) = 0$ and let $\bar{x}^S$ be such that $FMC^S_x(\bar{x}^S) = 0$; it is straightforward to show that $\bar{x} < \bar{x}^f < \bar{x}^S$. In other words, ignoring the safety effort costs tx_i, the per-unit cost-minimizing level of safety effort in the two-party case is less than a firm would choose in the three-party case, which is less than $\bar{x}^S$. Finally, we further assume that the properties of FMC carry over to FMC^f and FMC^S.

Market equilibrium and comparative statics

Denote the dependence of FMC^f on ϕ by $FMC^f(x;\ \phi)$; note that $FMC^f_{\phi}(x;\ \phi) = \tilde{v}(x) > 0$ and $FMC^f_{x\phi}(x;\ \phi) = \tilde{v}_x(x) < 0$. Thus, an increase in ϕ increases the firm's full marginal cost, but an increase in safety effort, x, can mitigate this effect. With a slight abuse of notation, we again consider the symmetric equilibrium and denote a firm's output level as q^n and its safety effort as x^n, which leads to equations analogous to (6) and (7), with $q^n(x^n;\ \phi)$ given by:

$$q^n(x^n;\phi) = (\alpha - FMC^f(x^n;\ \phi))/(2\beta + (n\text{-}1)\gamma), \tag{11}$$

and the equilibrium x^n given (implicitly) by:

$$- Nq^n(x^n;\phi)FMC^f_x(x^n;\phi)\{1 + \gamma^2(n\text{-}1)/[(2\beta - \gamma)(2\beta + (n\text{-}1)\gamma)]\} - t = 0. \tag{12}$$

It can be shown that x^n behaves in a qualitatively similar fashion with respect to the parameters t, N, β, α, and n as it did in the two-party case. Furthermore, since γ^{min}, the turning point for each of the curves displayed in Figure 1, is a function only of β and n, a diagram similar to Figure 1 would illustrate the market equilibrium safety effort levels in the three-party case. In fact, the turning points would occur at exactly the same values of γ, so $\mathrm{d}x^n/\mathrm{d}\gamma < 0$ when $\gamma < \gamma^{min}$, while $\mathrm{d}x^n/\mathrm{d}\gamma > 0$ when $\gamma > \gamma^{min}$. Also, it can be shown that the equilibrium output level, q^n, responds in a qualitatively similar manner as in the two-party case, for the parameters t, N, β, α, n, and γ.

In what follows, we will be especially interested in the effect of changes in ϕ on both the equilibrium quantity of the product provided and on the equilibrium level of safety investment made. This is because there are two avenues by which the spillover of harm from consumption can be influenced: via changes in the amount of the good sold and via changes in the level of safety provided. Of course, as both q and x change, this feeds back and affects the consumers of the product as well. As shown in the Appendix, if $\mathrm{d}x^n/\mathrm{d}\phi < 0$, then $\mathrm{d}q^n/\mathrm{d}\phi < 0$; that is, if an increase in the spillover rate ϕ were to result in a reduction in the equilibrium investment in safety effort, then this would be accompanied by a decrease in the quantity of output produced.

Also as shown in the Appendix (and suppressing arguments, but evaluating the expression at the equilibrium), $\mathrm{d}x^n/\mathrm{d}\phi > 0$ if and only if $FMC^f_x FMC^f_\phi > (\alpha - FMC^f)FMC^f_{x\phi}$. Since $FMC^f_x < 0$, $FMC^f_\phi = \tilde{v}$ and $FMC^f_{x\phi} = \tilde{v}_x$, then letting $q^n_x \equiv \partial q^n/\partial x^n$ yields the following result:

$$\mathrm{d}x^n/\mathrm{d}\phi > 0 \text{ if and only if } |\tilde{v}_x x^n/\tilde{v}| > q^n_x x^n/q^n. \tag{13}$$

Multiplying the denominator and numerator of the term $\tilde{v}_x x^n/\tilde{v}$ by $N\phi$ reveals that the resulting term in the absolute value is the elasticity of the firm's expected per-unit third-party liability costs with respect to an increase in the equilibrium safety level. Since $\tilde{v}_x < 0$, this elasticity is negative so that an increase in safety effort reduces these expected costs. The second term, $q^n_x x^n/q^n$, is the elasticity of the subgame-perfect equilibrium output with respect to x^n. Note that an increase in x^n results in an increase in the equilibrium q^n; this partially offsets the liability reduction due to an increase in safety effort. Thus, if the liability-related costs are more responsive (in percentage terms) to safety effort adjustments than is the equilibrium output in the quantity subgame, the firm will increase its safety investment in response to an increase in ϕ.[20]

Examining the first-order-conditions from the earlier analyses indicates that $x^n \rightarrow \bar{x}^f$ for large N, large α and for small t. Since $x^n = \bar{x}^f$ implies that $q^n_x = 0$, then it must be that $\mathrm{d}x^n/\mathrm{d}\phi > 0$ and $\mathrm{d}q^n/\mathrm{d}\phi < 0$; by continuity, this will also hold for x^n close enough to $\bar{x}^f$, due to large N, large α or small t. In this case, third-party harms will be reduced because the firm adjusts both instruments so as to reduce its overall exposure to liability for these losses: for t small (or large N or large α), firms will now produce a smaller quantity of safer products.

On the other hand, if the expected per-unit liability costs are less responsive to changes in x than is the subgame equilibrium output, then the firm will reduce its safety investment when ϕ increases. In this case, since $\mathrm{d}x^n/\mathrm{d}\phi < 0$, so is $\mathrm{d}q^n/\mathrm{d}\phi$: the firm reduces its overall exposure to liability by reducing output, but it also reduces the safety of the products sold.

Finally, note that an alternative to (13) can be shown to be the following:

$$\mathrm{d}x^n/\mathrm{d}\phi > 0 \text{ if and only if } \mathrm{d}(N\phi q^n \tilde{v})/\mathrm{d}x^n < 0. \tag{14}$$

That is, the response of the equilibrium level of safety to an increase in ϕ will be positive if and only if increasing x^n results in a reduction in overall liability costs for the firm associated with the negative externalities of their product. We summarize the foregoing in Proposition 3.

Proposition 3. In the n-firm symmetric safety effort equilibrium when there are third parties:

i) per customer output for each firm, $q^n(x^n)$, is given by equation (11) and is increasing in N and α, decreasing in t, β, n, and γ (for $\gamma \leq \gamma^{min}$);

ii) safety effort at each firm, x^n, is defined (implicitly) by equation (12) and is increasing in N, α, and γ (for $\gamma > \gamma^{min}$), and decreasing in t, β, n, and γ (for $\gamma < \gamma^{min}$);

iii) $\partial\gamma^{min}(\beta, n)/\partial n > 0$ and $\lim_{n\to\infty}\gamma^{min}(\beta, n) = \beta$;

iv) per-unit cost-minimizing safety effort increases relative to the two-party case: when $\phi > 0$, then $\bar{x} < \bar{x}^f$. However, $x^n < \bar{x}^f$, so that $FMC^f_x(x^n) < 0$;

v) $\mathrm{d}x^n/\mathrm{d}\phi > 0$ if and only if $|\tilde{v}_x x^n/\tilde{v}| > q^n_x x^n/q^n$ (i.e., if and only if $\mathrm{d}(N\phi q^n\tilde{v})/\mathrm{d}x^n < 0$);

vi) if $\mathrm{d}x^n/\mathrm{d}\phi < 0$ then $\mathrm{d}q^n/\mathrm{d}\phi < 0$.

Market equilibrium and social optimality in the three-party case

The conditions for social optimality when $t > 0$ are quite complex; we provide them, and a comparison with the foregoing market equilibrium, in the Appendix. Here we report the effect of third-party harms on the "crossing point," denoted $\Gamma^{nq}(\beta, n)$, that was identified in Section 4; in the two-party case, firms in market equilibrium under-supply safety (relative to *RSP*) if and only if $\gamma < \Gamma^{nq}(\beta, n)$. Just as the effect of ϕ on equilibrium safety x^n is dependent upon an elasticity comparison, so is the effect of ϕ on the range of γ-values for which the market under-supplies safety effort. It is shown in the Appendix that an increase in ϕ (from zero) leads the market to under-supply safety effort for a larger range of γ-values if and only if the magnitude of the elasticity of the uncompensated harm of third parties (with respect to safety effort) is larger than the elasticity of subgame-perfect equilibrium output. Thus:

$$x^n < X^{nq} \text{ at } \gamma = \Gamma^{nq}(\beta, n) \text{ if and only if } |\tilde{u}_x x^n/\tilde{u}| > q^n_x x^n/q^n. \tag{15}$$

On the other hand, if output is more responsive (in percentage terms) than is the uncompensated harm of third parties, then the market will over-provide safety effort for a larger range of γ-values.

Alternatively, and by the same process as used to produce (14), one can readily show that:

$$x^n < X^{nq} \text{ at } \gamma = \Gamma^{nq}(\beta, n) \text{ if and only if } \mathrm{d}(N\phi q^n\,\tilde{u})/\mathrm{d}x^n < 0. \tag{16}$$

Thus, the market equilibrium under-invests in safety effort (for a larger set of γ-values) in comparison with that level which *RSP* would choose if and only if increasing the level of safety effort would diminish total expected uncompensated losses for third parties.

Using the elasticity versions, we consider what appear to be the two most plausible cases:

Case 1. $|\tilde{v}_x x^n/\tilde{v}| > q^n_x x^n/q^n$ and $|\tilde{u}_x x^n/\tilde{u}| > q^n_x x^n/q^n$;

Case 2. $|\tilde{v}_x x^n/\tilde{v}| < q^n_x x^n/q^n$ and $|\tilde{u}_x x^n/\tilde{u}| < q^n_x x^n/q^n$.

In Case 1, equilibrium safety investment increases with third-party exposure and an increase in exposure (increasing ϕ from zero) leads the market to under-supply safety effort for a larger range of γ-values. An example of a product which might satisfy these conditions is retail gasoline, where a significant investment in safety effort involves the construction of the underground storage tank. Greater investment in the form of better seals, and walls that are thicker or more resistant to earth movement will not affect (by much) the safety of the gas station relative to consumers, but will significantly reduce the harms to third parties caused by gas leaking into the nearby water table. Moreover, if the choke price for gasoline (α) is high, then the subgame-perfect equilibrium output elasticity will be small, and this case is likely to obtain.

In Case 2, equilibrium safety effort and output decrease with an increase in third-party exposure and an increase in exposure (increasing ϕ from zero) leads the market to under-supply safety effort for a smaller range of γ-values. In this case, *RSP* has seemingly perverse incentives to want a lower safety effort level than that provided by the market (for a greater range of γ-values) because of the relatively high output-elasticity and relatively low responsiveness of third-party harm to safety effort. This is because higher x induces a substantial expansion in q, with relatively little reduction in third-party harm (per unit of output), making the increased use of safety effort counterproductive. Alternatively put, in this case a reduction in x (from the market equilibrium level) would induce a substantial reduction in q, with relatively little increase in third-party uncompensated loss (per unit of output). Thus, the overall result is a reduction in third-party harm. Note that this indirect means of reducing third-party harm reflects *RSP*'s inability to control q directly.

A product which might satisfy these conditions is a drug which may have some unpleasant or annoying side effects for the consumer (and for which the relationship between safety effort and amelioration is understood), but which also has a rare side effect that can lead the consumer to harm a third party. It has been argued that the prescription sleeping pill Halcion has (on rare occasions) induced a paranoid reaction, sometimes resulting in homicide (see Myers, 1993). If this rare side effect is not responsive to safety effort (perhaps because its mechanism is poorly-understood), then the output-elasticity with respect to safety could well exceed those related to third-party harm.

Market equilibrium and social optimality in the three-party case when t is small

The analysis above showed that market configurations (i.e., γ and n) which would result in over-investment in safety effort in the two-party setting (i.e., when $\gamma > \Gamma^{nq}(\beta, n)$) might now reflect under-investment if there were a negative externality associated with product consumption. In this section we highlight this issue by focusing on circumstances wherein x^n is close to $\bar{x}^f$; recall from above that this is associated with large N, large α, or small t. In what follows, we will take $t = 0$, discuss the resulting choices of x^n and X^{nq}, and then argue that (by continuity) qualitatively similar results will hold for t in a neighborhood of zero (or for t larger, but N or α sufficiently large).

When $t = 0$, it is immediate that $x^n = \bar{x}^f$. Under the assumption that $t = 0$, *RSP*'s optimal safety effort level is implicitly defined by:

$$- (\alpha - FMC^f(X^{nq}))FMC_x^f(X^{nq})$$
$$+ \phi [(2\beta + (n-1)\gamma)/(3\beta + (n-1)\gamma)][\tilde{u}(X^{nq})FMC_x^f(X^{nq}) - \tilde{u}_x(X^{nq})(\alpha - FMC^f(X^{nq}))] = 0. \quad (17)$$

If (17) is evaluated at $\bar{x}^f$, then $FMC_x^f = 0$ and the left-hand-side is positive, meaning that $X^{nq} > \bar{x}^f$. Thus, when $t = 0$, the market always supplies too little safety from the perspective of *RSP*, independent of γ and n, when there are risks to third parties. Moreover, this means that $FMC_x^f(X^{nq}) > 0$; that is, *RSP* would prefer the firm to operate on the <u>upward</u>-sloping portion of FMC^f.[21]

6. Implications of tort reform for the equilibrium safety effort and welfare

As was outlined in Section 2, harms (whether of consumers or third parties) result in lawsuits, which lead to settlement negotiations and, possibly, trial. Thus, policies that affect the settlement and litigation subgame can affect the equilibrium levels of safety effort, output and product price. In this section we summarize such a subgame (details are provided in the Appendix) and then examine the effect of three important parameters of the subgame on welfare.

The three parameters of interest are the total court costs incurred by the parties (K), the likelihood that P wins at trial (denoted as σ) and the maximum allowed compensation (denoted as δ^{max}). These parameters reflect the cost of adjudication (lower K means litigation is less costly), the evidentiary standard employed to find D liable (lower σ is associated with a higher evidentiary standard, making it less likely that P will win) and "caps" on compensation (lower δ^{max} is associated with tighter caps on compensation, meaning a lower expected award at trial). Lower values of K, σ and δ^{max} have the effect of lowering expected trial costs; interestingly, there are conditions under which <u>increasing</u> expected trial costs (via increases in K, σ, or δ^{max}) makes overall welfare increase.

When allowing for private information, it is traditional in this literature[22] to consider one-sided incomplete information and to focus on two possible forms for the resulting settlement bargaining game, one wherein P moves first and one wherein D moves first.[23] As described above, the game with P as first mover is a signaling game (since P has private knowledge of the level of damages, δ) while the game with D as first mover is a screening game (since D is uninformed about the actual level of damages).[24] In such games trials occur with positive probability due to the presence of private information.

The Appendix provides details of a signaling game wherein we have made specific functional form assumptions in order to provide sufficient structure to sign the relevant derivatives. The Appendix provides the equations for the expected trial costs given harm has occurred, $ETC(x; K, \sigma, \delta^{max})$, the plaintiff's expected losses given a harm has occurred, $EL_P(x; K, \sigma, \delta^{max})$, and the defendant's expected losses given a harm has occurred, $EL_D(x; K, \sigma, \delta^{max})$. These are then employed to generate signs for the derivatives of FMC (and FMC^f) with respect to x and the parameters. Focusing on each parameter separately (denoted as b), let $FMC(x; b) \equiv m(x) + \hat{\theta}(x)[\hat{\delta}(x) + ETC(x; b)]$ and let $FMC^f(x; b) \equiv FMC(x; b) + \phi\tilde{v}(s; b)$, for $b = K, \sigma, \delta^{max}$.

One critical result is that $FMC_b > 0$ and $FMC_b^f > 0$, for $b = K, \sigma, \delta^{max}$. Although an increase in K encourages settlement, it also makes those cases that do proceed to trial more costly; on net, an increase in K raises total expected trial costs, as well as the trial-related costs borne by the defendant. An increase in σ or δ^{max} increases the value of the plaintiff's case, which ultimately raises total expected trial costs (as settlement occurs less often) as well as the defendant's expected liability costs. Thus an increase in any of these parameters will increase the firm's full marginal costs.

However, it can be shown that $FMC_{bx} < 0$ and $FMC_{bx}^f < 0$ for $b = K$ and δ^{max}, so an increase in safety effort x can mitigate these cost increases. The impact of σ on FMC_x is more complex, but if the likelihood of an accident is sufficiently responsive to changes in x (see the Appendix), an increase in x also ameliorates the cost increases associated with higher σ; that is, $FMC_{\sigma x} < 0$ and $FMC_{\sigma x}^f < 0$. An example is the Ford Motor Company's design of the Pinto. Viscusi (1991) discusses the design flaw in the Pinto, wherein the company placed the gas tank only six inches from the rear bumper (which is unusually close to the rear bumper); a modification that would have dramatically reduced the likelihood of a gas tank rupture would have cost \$11 per car (Viscusi, 1991, p. 111). This suggests that, in the case of the Pinto, the elasticity of the likelihood of harm with respect to safety effort is probably large, and thus we might find in such a case that $FMC_{\sigma x} < 0$.

Note that this same sign pattern arose in our consideration of the effects of the third-party exposure rate ϕ on x^n, and thus the same kind of elasticity comparison is involved here. An increase in $b = K, \sigma$, or δ^{max} results in an increase in safety effort x^n if and only if the cost increase FMC_b^f is more responsive to an increase in safety effort than is the subgame equilibrium output. That is:

Proposition 4. $dx^n/db > 0$ if and only if $|FMC_{bx}^f x^n / FMC_b^f| > q_x^n x^n / q^n$, for $b = K, \sigma, \delta^{max}$.

We now ask whether the policies discussed above (promoting alternative dispute resolution, which reduces K; increased evidentiary standards, which corresponds to reducing σ; and caps on damages awards, which corresponds to reducing δ^{max}) can increase welfare.

Let $W(Q,X)$ be the planner's objective function:

$$W(Q,X) = N[n(\alpha Q - \beta Q^2/2 - (n\text{-}1)\gamma Q^2/2) - nFMC^S(X)Q] - ntX.$$

To see whether increases in a b-parameter are welfare-enhancing, evaluate this function at the non-cooperative equilibrium, parametrized by b: $W(q^n(x^n(b); b), x^n(b); b)$, where $b = K$, δ^{max} or σ. Thus:

$$dW/db = [(\partial W/\partial q^n)(\partial q^n/\partial x^n) + \partial W/\partial x^n](dx^n/db) + (\partial W/\partial q^n)(\partial q^n/\partial b) + \partial W/\partial b.$$

This derivative includes three terms. The first term is the product of dx^n/db and *RSP*'s first-order condition for safety effort (the term in square brackets), which is negative (positive) if $x^n >$ (<) X^{nq}. Since $\partial q^n/\partial b < 0$, the second term above is negative (positive) if $\partial W/\partial q^n >$ (<) 0 or, equivalently, if the welfare-maximizing output level $Q^n(x^n) = (\alpha - FMC^S(x^n))/(\beta + (n\text{-}1)\gamma)$ is greater than (less than) $q^n(x^n)$. The third term is always negative, since an increase in b increases full marginal social costs.

First, consider the two-party case. Since non-cooperative firms always produce too little output (for a given level of safety effort), both the second and third terms above are negative. Moreover, the first term is also negative if $x^n > X^{nq}$ and $dx^n/db > 0$ (or if $x^n < X^{nq}$ and $dx^n/db < 0$). Thus, for markets in which an increase in litigation costs increases safety effort (e.g., for sufficiently low t or sufficiently high N or α) and for which safety effort is already close to, or exceeds, what *RSP* would choose (e.g., for sufficiently large γ or n; see Figure 2), then proposed tort reforms (which would lower K, σ or δ^{max}) would be welfare-improving.

On the other hand, in the three-party case we have argued that $x^n < X^{nq}$ is likely to hold in markets wherein the rate of exposure of third parties (or the resulting uncompensated loss) is sufficiently high (at least for sufficiently low t or sufficiently high N or α, in which case the elasticity condition in equation (15) holds). Thus, in the three-party case the term in square brackets in the expression for dW/db can readily be positive. Moreover, when the rate of exposure of third parties (or the resulting uncompensated loss) is sufficiently high, then non-cooperative equilibrium output can readily exceed the socially optimal output (that is, $q^n(x^n) > Q^n(x^n)$), because the firm does not face the full marginal social cost. Thus, the first and second terms of dW/db can be positive, although the third term will always be negative. Consequently, tort reforms that are welfare-enhancing in the two-party case can be welfare-impairing in the three-party case if third-party exposure or uncompensated harms are significant. Alternatively put, in the three-party case, increases in K, δ^{max} or σ (all of which increase expected trial costs and are, in this sense, "wasteful") are welfare-enhancing if they induce a sufficiently large increase in safety effort, and if the third-party spillovers are sufficiently important.

7. Summary and implications of the analysis

This paper develops and examines a model of oligopolistic competition, with products that are both horizontally and vertically differentiated, to analyze the effect of market and legal incentives on the level of safety effort as well as the level of output. Consumption of these products may lead to harm (to consumers and/or to third parties), lawsuits, and compensation, either via settlement or trial. Firm-level costs reflect both safety investment and production activities, as well as liability-related costs. Compensation for victims is incomplete, both because of inefficiencies in the bargaining process and (possibly) because of statutorily-established limits on awards.

We compare the market equilibrium safety effort and output levels with what a planner who is able to set safety standards, but takes the market equilibrium output as given, would choose. We argue that this restricted planner is representative of what the tort system might do if faced with deciding upon a safety effort standard. Thus, our analysis incorporates market and legal incentives and allows us to examine the interplay of these two mechanisms.

The presence of (endogenously determined) fixed costs associated with safety effort means that output and safety effort choices are interdependent. This results in distortions between the equilibrium and (restricted) socially optimal levels of safety investment. Moreover, the levels of safety effort provided are affected both by the degree of substitutability of the products as well as the number of firms in the industry, a result not available from a model based on monopoly or perfect competition. In the two-party case, when the degree of product substitution is low, the market provides too little safety, but when the degree of product substitution is sufficiently high, the market over-provides safety. Furthermore, as the number of firms (and substitutable products) increases, the minimal degree of substitution such that firms provide (at least) the socially optimal level of safety decreases, meaning that weaker substitutability of products still can lead to sufficient safety effort. When third-party harms are added to the analysis, this continues to hold as long as the degree of spillover is sufficiently small, but equilibrium safety effort is always inefficiently low for products with large spillovers. This difference is due to the fact that while a consumer's willingness to pay is influenced by the firm's safety effort, non-consumers do not enter the market, so their losses are not directly accounted for by the firm, which means that the distortion between equilibrium and optimality occurs even if the unit cost of safety effort is zero.

Thus, while the primary incentives for investment in safety effort come from the market in the two-party case, legal incentives play a greater role in the case wherein product consumption exposes third parties to harm. We show that firms that face liability for third-party harms will increase investment in safety effort in response to increases in the exposure rate when such increases reduce the firm's total losses due to settlement and litigation with third parties. Equivalently, this investment increases in response to the exposure rate as long as the magnitude of the elasticity of the firm's third-party liability costs (with respect to safety effort) exceeds the elasticity of per-consumer output (with respect to safety effort). Moreover, the restricted planner prefers that the firm increase its investment as long as such increases reduce third parties' total uncompensated losses due to harm, settlement and litigation with firms.

Furthermore, the use of the tort system involves costs, sometimes significant in size, and this has led to calls for changes in that system. Tort reform is frequently posed in terms of victims versus injurers, with injurers the likely beneficiaries of, and victims the almost certain losers from, such reforms. Our analysis suggests that consumer victims and injurers in markets with enough firms, product substitutability, and usable safety information, so that the equilibrium level of safety effort meets or exceeds the restricted social planner's desired level, would both benefit from reform. It also suggests that agents in those settings wherein this is not true would, at least in aggregate, be harmed by such reforms, and that this situation is most likely to occur when there are substantial spillovers, or just a few firms producing highly differentiated products.

Thus, the sort of sweeping undifferentiated tort reform currently under consideration is unlikely to be uniformly welfare-enhancing. We envision two possible ways to "fine-tune" the use of tort reforms; one involves distinguishing between types of products, while the other involves distinguishing between types of plaintiffs.

One could distinguish between types of products based on whether or not consumption of the product is likely to generate third-party harms, and then apply tort reform only in markets without significant spillovers to third parties. When victims of harm are primarily consumers of the product, market incentives are more likely to result in sufficient (or even excessive) safety effort. In this case, tort reforms that lower expected trial costs will benefit both consumers and firms by saving costs and moving safety effort closer to the optimum. This distinction is imperfect because even in the two-party case, Figure 2 illustrates how a small number of firms or a low degree of product substitution may mean that market incentives are too weak to encourage sufficient safety investment. When there are significant spillovers to third parties, then safety effort investment is more likely to be inadequate (at least for large N or α, or small t, see Section 5), and thus tort reform could exacerbate this under-investment. Moreover, the model's analysis rests on the assumption that consumers are rational and will seek, and can effectively use, safety information. Thus, for example, while malpractice is typically a two-party issue, the limited information most consumers have about doctor (or hospital) quality may make applying tort reform in this particular product market inadvisable.

The market for restaurant meals seems likely to provide sufficient safety effort since: (1) people have the opportunity to become informed about restaurant-specific safety through local reputation and (often) publically-available health inspection reports; (2) the onset of illness from restaurant food is usually swift, and limited to the household (thus, this is essentially a two-party situation); (3) there are usually a significant number of restaurants that are relatively close substitutes, so competitive incentives for improved safety come into play. Jin and Leslie (2003) examined the use of posted restaurant hygiene information by consumers and found that the information was used by consumers when selecting a restaurant and that this led to improvements in hygiene by firms. Thus (assuming that higher legal system costs would induce greater safety effort), policies that reduce the costs of the legal system would seem desirable in this context. To the extent that such policies shift losses to consumers, the consumer can shift them back through their willingness to pay.

On the other hand, we have also discussed how safety effort in the retail gasoline market may have its primary effect on third parties, rather than consumers. Insofar as safety affects customers, again a local reputation may be developed, but safety effort that affects third parties (such as storage tank design) is unobservable to consumers and third parties, is irrelevant to consumers, and third parties are unable to use the market to shift their costs back to the firms. This suggests that safety effort is likely to be lower than a restricted social planner would choose, and thus (again, assuming that higher legal system costs would induce greater safety effort) policies that reduce the costs of the legal system would exacerbate the under-provision of safety, particularly if these policies shift losses from firms to victims (as occurs under higher evidentiary standards and damages caps). The retail gasoline example shows how even the presence of a large number of firms with readily substitutable products may not be sufficient when negative externalities are substantial.

Alternatively, one could distinguish between consumer and third-party victims, and invoke tort reforms (such as a cap on damages) only for cases involving consumer victims. This would allow firms and consumer victims to benefit from the reduced expected litigation costs associated with tort reform, while encouraging firms to invest in safety effort, potentially of a more targeted nature, to avoid harm to third parties. If a product primarily harms consumers (or primarily harms third parties), such a scheme would mimic the one that distinguishes between types of products. However, for products that generate harms to both consumers and third parties, this reform may still erode the firms' aggregate incentives to invest in safety, but less so the greater the number of third-party victims, and certainly to a lesser extent than the currently-proposed blanket application of tort reform.

References

Anderson, S.P. and de Palma, A. "Product Diversity in Asymmetric Oligopoly: Is the Quality of Consumer Goods Too Low?" Journal of Industrial Economics, Vol. 49 (2001), pp. 113-135.

Ballard, M. "Tort Reform Advances in Mississippi (for Starters): Action is Foreseen in Other States." National Law Journal, Vol. 25 (2003), p. A1.

Bebchuk, L.A. "Litigation and Settlement under Imperfect Information." RAND Journal of Economics, Vol. 15 (1984), pp. 404-415.

Boyer, M. and Porrini, D. "Modeling the Choice Between Regulation and Liability in Terms of Social Welfare." Working Paper, CIRANO, University of Montreal, Canada, 2002.

Caher, J. "Assembly Bill, Ad Blitz Help Raise the Stakes in Tort Reform Debate: State Mirrors National Agenda." New York Law Journal, Vol. 229, p. 1.

Cooter, R. and Ulen, T. Law and Economics, 4th Ed. Reading, MA: Pearson Addison Wesley, 2003.

Daughety, A.F. "Settlement." in B. Bouckaert and G. DeGeest, eds., Encyclopedia of Law and Economics, Vol. V. Northhampton, MA: Edward Elgar Publishing Co., 2000.

_____________ and Reinganum, J.F. "Product Safety: Liability, R&D and Signaling." American Economic Review, Vol. 85 (1995), pp. 1187-1206.

_____________ and _____________. "Informational Externalities in Settlement Bargaining: Confidentiality and Correlated Culpability." RAND Journal of Economics, Vol. 33 (2002), pp. 587-604.

Epple, D. and Raviv, A. "Product Safety: Liability Rules, Market Structure, and Imperfect Information." American Economic Review, Vol. 68 (1978), pp. 80-95.

Hamada, K. "Liability Rules and Income Distribution in Product Liability." American Economic Review, Vol. 66 (1976), pp. 228-234.

Hay, B. and Spier, K. "Settlement of Litigation," in P. Newman, ed., The New Palgrave Dictionary of Economics and the Law. New York: Stockton Press, 1998.

Jin, G.Z. and Leslie, P. "The Effect of Information on Product Quality: Evidence From Restaurant Hygiene Grade Cards." Quarterly Journal of Economics, Vol. 118 (2003), pp. 409-451.

Kamien, M.I., Muller, E. and Zang, I. "Research Joint Ventures and R&D Cartels." American Economic Review, Vol. 82 (1992), pp. 1293-1306.

Lewis, T.R. and Sappington, D.E.M. "Using Decoupling and Deep Pockets to Mitigate Judgment-Proof Problems." International Review of Law and Economics, Vol. 19 (1999), pp. 275-293.

Myers, T.P. "Halcion Made Me Do It: New Liability and a New Defense." University of Cincinnati Law Review, Vol. 62 (1993), pp. 603-653.

Polinsky, A.M. “Strict Liability versus Negligence in a Market Setting.” American Economic Review, Vol. 70 (1980), pp. 363-367.

_____________ and Rogerson, W.P. “Products Liability, Consumer Misperceptions, and Market Power.” RAND Journal of Economics, Vol. 14 (1983), pp. 581-589.

Posner, R.A. Economic Analysis of the Law, 5th Ed. New York, NY: Aspen Publishers, 1998.

Rea, S.A., Jr. “Penalty Doctrine in Contract Law.” in P. Newman, ed., The New Palgrave Dictionary of Economics and the Law. New York: Stockton Press, 1998.

Reinganum, J.F. and Wilde, L.L. “Settlement, Litigation, and the Allocation of Litigation Costs.” RAND Journal of Economics, Vol. 17 (1986), pp. 557-66.

Shavell, S. “Strict Liability versus Negligence.” Journal of Legal Studies, Vol. 9 (1980), pp. 1-25.

________. Foundations of Economic Analysis of Law. Cambridge, MA: Harvard University Press, 2004.

Spence, M. “Monopoly, Quality and Regulation.” Bell Journal of Economics, Vol. 6 (1975), pp. 417-429.

_________. “Consumer Misperceptions, Product Failure and Producer Liability.” Review of Economic Studies, Vol. 44 (1977), pp. 561-572.

Spulber, D.F. Regulation and Markets. Cambridge, MA: MIT Press, 1989.

VandeHei, J. “GOP Plans New Caps on Court Awards; Piecemeal, Republicans Have Limited Lawsuits Against Some Businesses.” Washington Post, Sunday, December 29, 2002, p. A5.

Viscusi, W.K. Reforming Products Liability. Cambridge, MA: Harvard University Press, 1991.

Appendix

We present some of the more technical derivations, prove some assertions made in the text, and present a settlement subgame model that yields continuation payoffs for the plaintiff and defendant that exhibit the properties specified in the text.

The firms' safety effort levels are strategic substitutes

To see this, first recall that for the case of two parties, equation (5), the first-order condition for firm i's choice of safety, can be written as:

$$- Nq_i^n FMC_x(x_i)\{2\beta[2\beta + (n\text{-}2)\gamma]/(2\beta - \gamma)[2\beta + (n\text{-}1)\gamma]\} - t = 0. \tag{A.1}$$

Since we assume that the reduced-form profit function is strictly concave in x_i, the following second-order condition also holds:

$$\begin{aligned} &- Nq_i^n FMC_{xx}(x_i)\{2\beta[2\beta + (n\text{-}2)\gamma]/(2\beta - \gamma)[2\beta + (n\text{-}1)\gamma]\} \\ &+ 2\beta N\{FMC_x(x_i)\}^2\{[2\beta + (n\text{-}2)\gamma]/(2\beta - \gamma)[2\beta + (n\text{-}1)\gamma]\}^2 < 0. \end{aligned} \tag{A.2}$$

Equation (A.1) implicitly provides firm i's best response to the vector of other firms' safety levels, x_{-i}, denoted $BR_i(x_{-i})$. In light of (A.2), the sign of dBR_i/dx_j is the same as the sign of $-N\{\partial q_i^n/\partial x_j\}FMC_x(x_i)\{2\beta[2\beta + (n\text{-}2)\gamma]/(2\beta - \gamma)[2\beta + (n\text{-}1)\gamma]\}$. This expression is negative, since $- FMC_x(x_i) > 0$ and $\partial q_i^n/\partial x_j = \gamma FMC_x(x_j)/(2\beta - \gamma)[2\beta + (n\text{-}1)\gamma] < 0$. Thus, $dBR_i/dx_j < 0$, so the firms' safety levels are strategic substitutes.

Comparative statics with respect to a parameter *b* affecting *FMC*

Two parties

Let $b \geq 0$ be a parameter that increases the full marginal cost per unit of output produced, but that increase can be mitigated by increasing x. If we denote this dependence by $FMC(x; b)$, then $FMC_b(x; b) > 0$ and $FMC_{bx}(x; b) < 0$. Also, let $H(x; a, b) = -(\alpha - FMC(x; b))FMC_x(x; b) - a$ and let x^* be defined implicitly by $H(x^*; a, b) = 0$. Note that this implies $FMC_x(x^*; b) < 0$, and we have already assumed that FMC is strictly convex; that is, $FMC_{xx} > 0$. Then we can determine the effect of an increase in b on x^* as follows: $\mathrm{d}x^*/\mathrm{d}b = -H_b/H_x$, where both numerator and denominator are evaluated at x^*. Since $H_x < 0$, the sign of $\mathrm{d}x^*/\mathrm{d}b$ is the same as the sign of $H_b = FMC_x FMC_b - (\alpha - FMC)FMC_{bx}$, and $H_b > 0$ if and only if $FMC_x/(\alpha - FMC) > FMC_{bx}/FMC_b$. Moreover, we can determine the effect of an increase in b on the associated output level, denoted q^*, as follows: $\mathrm{sgn}\{\mathrm{d}q^*/\mathrm{d}b\} = \mathrm{sgn}\{-FMC_b - FMC_x(\mathrm{d}x^*/\mathrm{d}b)\}$. This is negative if and only if $FMC_{bx}/FMC_b > FMC_{xx}/FMC_x$, where again all expressions are evaluated at x^*. This leads to the following results.

Result 1: $\mathrm{d}x^*/\mathrm{d}b > 0$ if and only if $FMC_x/(\alpha - FMC) > FMC_{bx}/FMC_b$.

Result 2: $\mathrm{d}x^*/\mathrm{d}b < 0$ implies $\mathrm{d}q^*/\mathrm{d}b < 0$; $\mathrm{d}x^*/\mathrm{d}b > 0$ implies

$$[\mathrm{d}q^*/\mathrm{d}b < 0 \text{ if and only if } FMC_{bx}/FMC_b > FMC_{xx}/FMC_x].$$

Note that $\mathrm{d}x^*/\mathrm{d}b < 0$ jointly with $\mathrm{d}q^*/\mathrm{d}b > 0$ is not possible. This would require that $FMC_x/(\alpha - FMC) < FMC_{bx}/FMC_b$ and $FMC_{bx}/FMC_b < FMC_{xx}/FMC_x$. These cannot hold simultaneously since they jointly imply that $FMC_{xx}/FMC_x > FMC_{bx}/FMC_b > FMC_x/(\alpha - FMC)$, which is ruled out by the condition $H_x = -(\alpha - FMC)FMC_{xx} + \{FMC_x\}^2 < 0$.

Consumer and third-party victims

Recall that the equilibrium safety effort level when there are consumer and third-party victims is defined implicitly by the equation $H^f(x^n; a^n, b) = -(\alpha - FMC^f(x^n; b))FMC^f_x(x^n; b) - a^n = 0$. Upon noting the similarity of this equation to the consumer-victim case, it is apparent that Results 1 and 2 are readily extended to the case of consumer and third-party victims by substituting FMC^f for FMC. Specifically, since ϕ influences FMC^f directly and via its effect on x^n, differentiating equation (11) in the text yields:

$$dq^n/d\phi = -[FMC^f_\phi(x^n; \phi) + (dx^n/d\phi)FMC^f_x(x^n; \phi)]/(2\beta + (n-1)\gamma).$$

Since $x^n < \bar{x}^f$, then $FMC^f_x(x^n; \phi) < 0$. Thus, it follows that if $dx^n/d\phi < 0$, then $dq^n/d\phi < 0$.

Social optimality with third parties and $t > 0$

We consider the choice of safety effort investment that a planner would make, assuming that the planner is restricted to take the resulting equilibrium output levels (and the number of firms) as given by the Nash equilibrium for that subgame. We consider only symmetric choices and assume that *RSP*'s problem is strictly concave in X. The restricted planner's problem is:

$$\max_X \{N[n(\alpha Q - \beta Q^2/2 - (n-1)\gamma Q^2/2) - nFMC^S(X)Q] - ntX|\, Q = q^n(X)\}.$$

Note that the restricted social planner faces $FMC^S(X)$, in contrast with each firm which only considers $FMC^f(x)$. Again, let (X^{nq}, Q^{nq}) solve *RSP*'s problem. Then (X^{nq}, Q^{nq}) satisfies the following conditions.

$$Q^{nq} = (\alpha - FMC^f(X^{nq}))/(2\beta + (n\text{-}1)\gamma), \tag{A.3}$$

and

$$\begin{aligned} &- (\alpha - FMC^f(X^{nq}))FMC^f_x(X^{nq}) - (t/N)[(2\beta + (n\text{-}1)\gamma)^2/(3\beta + (n\text{-}1)\gamma)] \\ &\quad + \phi\,[(2\beta + (n\text{-}1)\gamma)/(3\beta + (n\text{-}1)\gamma)][\tilde{u}(X^{nq})FMC^f_x(X^{nq}) - \tilde{u}_x(X^{nq})(\alpha - FMC^f(X^{nq}))] = 0. \end{aligned} \tag{A.4}$$

What happens now to the relationship between x^n and X^{nq}? If (counter-factually) $\tilde{u}(\bullet) = \tilde{u}_x(\bullet) = 0$, then (12) and (A.4) have the same solution for $\gamma = \Gamma^{nq}(\beta, n)$.[25] Since $\tilde{u}(\bullet) > 0$ and $\tilde{u}_x(\bullet) < 0$, the sign of the last term in (A.4) matters. Suppose the last square-bracketed term in the second line of equation (A.4) is positive at x^n; that is, $[\tilde{u}(x^n)FMC^f_x(x^n) - \tilde{u}_x(x^n)(\alpha - FMC^f(x^n))] > 0$. Then at $\gamma = \Gamma^{nq}(\beta, n)$, the solution to (12) is now less than the solution to (A.4); that is, at this value of γ, $x^n < X^{nq}$, so the equilibrium safety effort is now less than the (restricted) socially optimal level at $\gamma = \Gamma^{nq}(\beta, n)$. That is, the crossing point between the x^n curve and the X^{nq} curve has moved "rightward."

Alternatively, if $[\tilde{u}(x^n)FMC^f_x(x^n) - \tilde{u}_x(x^n)(\alpha - FMC^f(x^n))] < 0$, then the crossing point between the x^n curve and the X^{nq} curve has moved "leftward," so that the market equilibrium safety level exceeds the (restricted) socially optimal level at $\gamma = \Gamma^{nq}(\beta, n)$. Note that:

$$[\tilde{u}(x^n)FMC^f_x(x^n) - \tilde{u}_x(x^n)(\alpha - FMC^f(x^n))] > 0 \text{ if and only if } FMC^f_x(x^n)/(\alpha - FMC^f(x^n)) > \tilde{u}_x(x^n)/\tilde{u}(x^n).$$

Since $q^n_x/q^n = - FMC^f_x(x^n)/(\alpha - FMC^f(x^n))$, the inequality above holds if and only if $- q^n_x/q^n > \tilde{u}_x(x^n)/\tilde{u}(x^n)$ or, equivalently, if and only if $q^n_x x^n/q^n < |\tilde{u}_x(x^n)x^n/\tilde{u}(x^n)|$.

Summary of the settlement subgame and how its parameters affect full marginal cost

Two parties

In this section, we present a specific settlement subgame which satisfies the assumptions we have made in the text with respect to the signs of $\hat{\delta}_x$, $\hat{\delta}_{xx}$, ETC_x, ETC_{xx}, u_x, u_{xx}, v_x, and v_{xx}. We also focus on several parameters of this subgame and determine how they affect *FMC* so as to be able to describe their comparative static effects on (x^n, q^n) and (X^{nq}, Q^{nq}).

The settlement subgame is a version of Reinganum and Wilde's (1986) signaling game. In addition to the assumptions we have already made about the distributions of θ and δ, we assume that $G(\delta; x) = 1 - \exp\{-\mu(x)(\delta - \underline{\delta})\}$ for $\delta \in [\underline{\delta}, \infty)$, where $\mu_x > 0$ and $\mu_{xx} < 0$ and $\underline{\delta}$ is independent of x. This means that $\hat{\delta}(x) = \underline{\delta} + 1/\mu(x)$; thus $\hat{\delta}_x = -\mu_x/(\mu)^2 < 0$ and $\hat{\delta}_{xx} = [-\mu\mu_{xx} + 2(\mu_x)^2]/(\mu)^3 > 0$. We assume in addition that $\hat{\theta}_x < 0$ and $\hat{\theta}_{xx} > 0$, but we otherwise do not restrict the distribution $F(\theta; x)$.

In addition to the trial cost parameters, k_P and k_D (where $K \equiv k_P + k_D$), we introduce a parameter σ which represents, for example, the ease of demonstrating causality, and a parameter δ^{max}, which represents a cap on damage awards. If it is straightforward to prove that the product caused the harm, then $\sigma = 1$; if the link between the product and the harm is more difficult to establish, either for technological or for legal reasons, then $\sigma < 1$. Thus, a plaintiff with harm δ who goes to trial can expect to receive an award of $\min\{\sigma\delta, \sigma\delta^{max}\}$. We also assume that $\delta^{max} > \hat{\delta}(x) = \underline{\delta} + 1/\mu(x)$; that is, the damages cap exceeds average damages.

Following the analysis in Reinganum and Wilde (1986), the equilibrium settlement demand is given by $S = \min\{\sigma\delta, \sigma\delta^{max}\} + k_D$ and the equilibrium probability of trial is given by $r(\delta) = 1 - \exp\{-\sigma(\delta - \underline{\delta})/K\}$ for $\delta < \delta^{max}$ and $r(\delta) = 1 - \exp\{-\sigma(\delta^{max} - \underline{\delta})/K\}$ for $\delta \geq \delta^{max}$. Expected trial costs and expected losses for the plaintiff are easily computed to yield:

$$ETC(x; K, \sigma, \delta^{max}) = [\sigma K/(\sigma + \mu(x)K)](1 - \exp\{-[(\sigma + \mu(x)K)/K](\delta^{max} - \underline{\delta})\});$$

$$EL_P(x; K, \sigma, \delta^{max}) = \hat{\delta}(x) + ETC(x; K, \sigma, \delta^{max}) - k_D - \sigma\underline{\delta} - (\sigma/\mu(x))(1 - \exp\{-\mu(x)(\delta^{max} - \underline{\delta})\})$$
$$= \underline{\delta}(1 - \sigma) + (1/\mu(x))[1 - \sigma(1 - \exp\{-\mu(x)(\delta^{max} - \underline{\delta})\})] + ETC(x; K, \sigma, \delta^{max}) - k_D.$$

The bargaining model we have assumed allocates maximum bargaining power to the plaintiff, and thus it is technically possible (though implausible) for the plaintiff to expect to gain by being harmed (or by an increase in the combined cost of a trial, K). In order to ensure that $EL_P(x; K, \sigma, \delta^{max}) > 0$ (so the plaintiff does not expect to be over-compensated when harmed), we assume that $ETC(x; K, \sigma, \delta^{max}) - k_D > 0$. Taking $k_D = K/2$, this can be guaranteed by assuming that $\sigma/\mu(x) > K$ and that the cap δ^{max} is sufficiently large (specifically, $\delta^{max} > \underline{\delta} - [K/(\sigma + \mu(x)K)]\ln\{(\sigma - \mu(x)K)/2\sigma\}$). When $\sigma = 1$ and there is no cap, this reduces to $1/\mu(x) > K$, which is very plausible, as it assumes that the average amount of damages in excess of $\underline{\delta}$ exceeds the combined costs of trial. We maintain the assumption $\sigma/\mu(x) > K$ in what follows. We will need to strengthen this assumption below in order to ensure that $EL_P(x; K, \sigma, \delta^{max})$ does not decrease with an increase in K (i.e., so that increases in K are borne, in part, by each party). Finally,

$$EL_D(x; K, \sigma, \delta^{max}) = k_D + \sigma\underline{\delta} + (\sigma/\mu(x))(1 - \exp\{-\mu(x)(\delta^{max} - \underline{\delta})\}).$$

Under our maintained assumptions that $\delta^{max} > \hat{\delta}(x) = \underline{\delta} + 1/\mu(x)$ and $\sigma/\mu(x) > K$, it is tedious but straightforward to show that $ETC_x < 0$ and $ETC_{xx} > 0$, as assumed in the text. In addition,
(1) $ETC_K > 0$ and $ETC_{xK} < 0$; (2) $ETC_\sigma > 0$ and $ETC_{x\sigma} > 0$; and (3) $ETC_{\delta^{max}} > 0$ and $ETC_{x\delta^{max}} < 0$.

It is worth verifying that the properties $u_x < 0$, $u_{xx} > 0$, $v_x < 0$ and $v_{xx} > 0$ hold for this example. It can be shown that $EL_{Dx} < 0$ and $EL_{Dxx} > 0$; and $EL_{Px} < 0$ and $EL_{Pxx} > 0$. Since $v(x) = \hat{\theta}(x)EL_D(x)$, it follows that $v_x = \hat{\theta}_x EL_D + \hat{\theta}(x)EL_{Dx} < 0$ and $v_{xx} = \hat{\theta}_{xx}EL_D + 2\hat{\theta}_x EL_{Dx} + \hat{\theta}(x)EL_{Dxx} > 0$, as assumed in the text. Similarly, since $u(x) = \hat{\theta}(x)EL_p(x)$, it follows that $u_x = \hat{\theta}_x EL_P + \hat{\theta}(x)EL_{Px} < 0$ and $u_{xx} = \hat{\theta}_{xx}EL_P + 2\hat{\theta}_x EL_{Px} + \hat{\theta}(x)EL_{Pxx} > 0$, as assumed in the text.

Other comparative static effects of EL_D and EL_P are: (4) $EL_{DK} > 0$ and $EL_{DxK} = 0$; (5) $EL_{D\sigma} > 0$ and $EL_{Dx\sigma} < 0$; (6) $EL_{D\delta^{max}} > 0$ and $EL_{Dx\delta^{max}} < 0$; (7) $EL_{PK} > 0$ (assuming $\sigma/\mu(x) > K/(2^{1/2} - 1)$ and the cap δ^{max} is sufficiently large) and $EL_{PxK} < 0$; (8) $EL_{P\sigma} < 0$ and $EL_{Px\sigma} > 0$; and (9) $EL_{P\delta^{max}} < 0$ and $EL_{Px\delta^{max}} > 0$.

Thus, both *P* and *D* suffer higher expected losses if the cost of a trial increases. An increase in σ or δ^{max}, both of which shift losses from *P* to *D* (but also raise expected trial costs) end up, on net, increasing *D*'s expected losses and decreasing *P*'s expected losses.

Since $FMC(x; K, \sigma, \delta^{max}) = m(x) + u(x) + v(x) = m(x) + \hat{\theta}(x)[\hat{\delta}(x) + ETC(x; K, \sigma, \delta^{max})]$, it follows that $FMC_{xx} > 0$. Moreover, (10) $FMC_K > 0$ and $FMC_{xK} < 0$; (11) $FMC_\sigma > 0$ and $FMC_{x\sigma} < 0$ (> 0) as $\hat{\theta}_x ETC_\sigma + \hat{\theta}(x)ETC_{x\sigma} < 0$ (> 0); and (12) $FMC_{\delta^{max}} > 0$ and $FMC_{x\delta^{max}} < 0$.

Consumer and Third-Party Victims

Recall that $FMC^f(x)$ can be written as: $FMC^f(x; \phi) = FMC(x) + \phi\tilde{v}(x)$. Therefore, it follows that $FMC^f_\phi > 0$ and $FMC^f_{\phi x} < 0$. Moreover, the properties of FMC^f with respect to the parameters K, σ and δ^{max} are the same as those of *FMC* (as given in (10)-(12)) with the possible exception of $FMC^f_{\sigma x} = FMC_{\sigma x} + \phi\tilde{v}_{\sigma x}$. Since the second term is negative, $FMC^f_{\sigma x} < 0$ if $FMC_{\sigma x} < 0$; otherwise, the sign of $FMC^f_{\sigma x}$ may be positive. Similarly, $FMC^S(x) \equiv FMC(x) + \phi(\tilde{u}(x) + \tilde{v}(x))$. Therefore, it follows that $FMC^S_\phi > 0$ and $FMC^S_{\phi x} < 0$. Moreover, the properties of FMC^S with respect to the parameters K, σ and δ^{max} are exactly the same as those of *FMC* (as given in (10)-(12)).

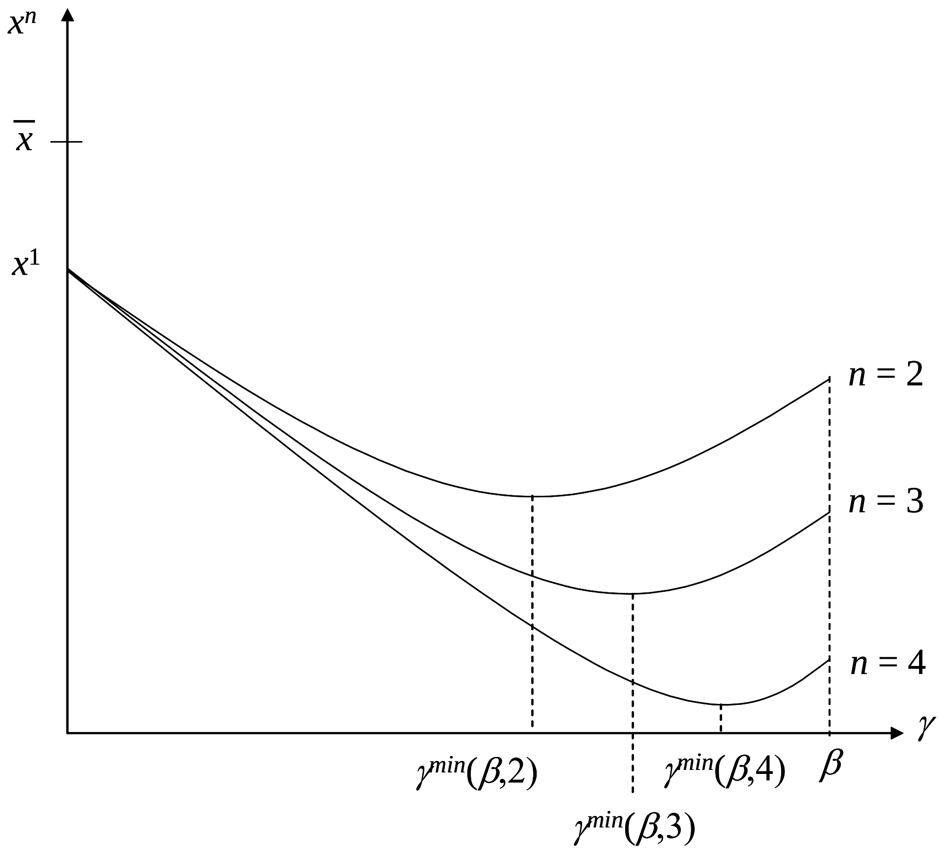

Figure 1: Behavior of Safety Effort (x^n) as a function of γ and n

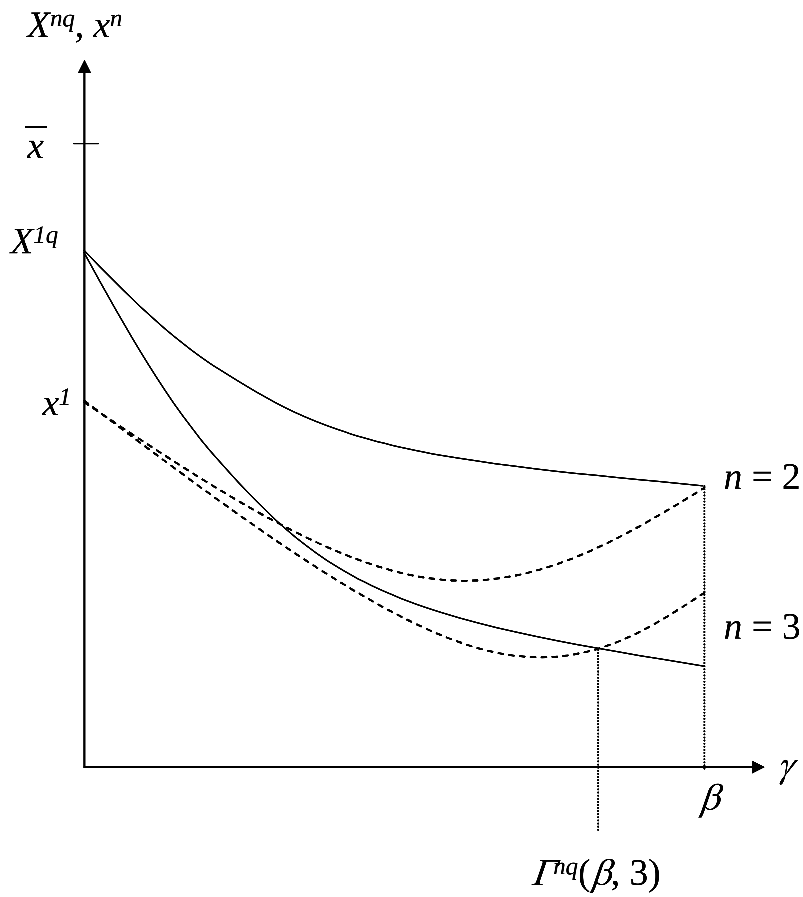

Figure 2: Comparison of Socially Optimal and Equilibrium Safety Effort

Endnotes

1. At the end of Section 4 we briefly discuss how our market equilibrium results would change if the firms chose prices instead of quantities.

2. In the Web Appendix we consider a less restricted social planner who can choose both safety effort and output. The comparison of equilibrium safety effort with this less restricted social planner's preferred level is qualitatively similar to that of the restricted planner presented in the main text, although there are minor quantitative differences.

3. Here consumers bear residual harm and litigation costs, but subtract these losses from their willingness to pay. The slope of the demand curve is unaffected by safety and the combined marginal production and liability costs are decreasing in safety at the firm's optimum, so a monopolist always under-provides safety; this need not hold for an oligopoly.

4. Other papers that assume a constant safety expenditure per unit of output and strict liability include Hamada (1976) and Epple and Raviv (1978). Shavell (1980) examines a variety of liability rules and bilateral safety effort. Polinsky (1980) further shows that under strict liability (and costless litigation) the equilibrium number of firms is socially optimal.

5. A related literature uses a different (logit) demand structure and price strategies; see Anderson and de Palma (2001). They show that firms might under-provide quality when higher quality requires a higher fixed cost. We show that, with quantity strategies, firms may over-provide quality as a competitive attribute.

6. Available at http://www.rje.org/main/sup-mat.html.

7. Although we are assuming strict liability throughout this paper, in reality firms' tort liability is sometimes based on a negligence criterion.

8. The use of *x*, or a parameter, as a subscript on a function indicates differentiation.

9. For now, harm and cause will be obvious (though the level of harm in terms of damages is a consumer's private information). Thus, we abstract from details such as evidentiary considerations about proving that a firm's product caused a harm; we return to this later.

10. The value of this restriction to quadratic utility functions is that inverse demand functions are linear in quantity, making the multi-stage computations and comparisons more transparent. Quasilinearity guarantees that the demand functions are independent of the level of consumer income, as long as consumers have sufficient income.

11. Spence (1977), Shavell (1980, 2004) and Polinsky and Rogerson (1983) analyze liability when consumers mis-perceive safety level. Spence (1977) argues that "voluntary liability" (not price) may serve as a signal of safety. Daughety and Reinganum (1995) argue that liability is largely imposed by the tort system; they provide a model in which price signals quality.

12. By assuming that F and G satisfy FOSD in x we know that $\hat{\theta}_x(x) \leq 0$, $\hat{\delta}_x(x) \leq 0$ and therefore $[\hat{\theta}(x)\hat{\delta}(x)]_x \leq 0$. If $ETC(x)$ is strictly decreasing in x then $u_x(x) + v_x(x) < 0$. Assumption 1 reflects a strengthening of these

properties.

13. We assume there is no risk of bankruptcy. A growing literature on extended liability addresses this issue; see, for example, Lewis and Sappington (1999) and Boyer and Porrini (2002).

14. This profit function resembles that in the cost-reducing R&D literature (see Kamien, Muller and Zang, 1992). There, x reduces marginal production costs. Here marginal production costs increase in x, but since marginal liability costs decrease in x, FMC is U-shaped in x. We indicate below some results that are common to the two literatures.

15. Spulber (1989, p. 409) makes this observation in the monopoly case.

16. Moreover, safety effort levels are strategic substitutes; that is, using (5) and firm i's second-order condition, it can be shown that $dx_i/dx_j < 0$ for $j \neq i$. See the Appendix for details.

17. Equation (7) is similar to equation (9) in Kamien, Muller and Zang (1992), who focus on a "knowledge-spillover" parameter (absent here) and do not examine comparative statics with respect to parameters of interest here (n, γ, and those affecting FMC). Moreover, they compare equilibrium R&D investment with that of a research joint venture, not a social planner.

18. $\gamma^{min}(\beta, n) = 2\beta/3$ for $n = 2$, and $\gamma^{min}(\beta, n) = \beta[n - 5 + (n^2 - 2n + 9)^{½}]/2(n-2)$ for $n > 2$.

19. It is straightforward to show that $\Gamma^{nq}(\beta, n) = \beta([8n - 7]^{½} - 1)/(2(n-1))$. Note that, the fact that $\Gamma^{nq}(\beta, 2) = \beta$ is most likely a result of the assumed functional forms.

20. The equilibrium quantity may increase or decrease; for precise conditions, see the Appendix.

21. Indeed, it is possible for $X^{nq} > \bar{x}^S$; see the Web Appendix.

22. For reviews of this literature, see Hay and Spier (1998) and Daughety (2000).

23. The games are "ultimatum" games: the first mover makes an offer and the second mover chooses to accept or to reject. If the second mover chooses to reject, both parties go to trial where a court correctly determines the relevant private information and makes the appropriate transfer.

24. Bebchuk (1984) analyzes the screening version while Reinganum and Wilde (1986) analyzes the signaling version.

25. Recall that $\Gamma^{nq}(\beta, n)$ provided the "crossing point" for the market equilibrium and (restricted) socially optimal safety levels in the absence of third parties; see Section 4 for details.