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**Markets, Torts and Social Inefficiency**

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### ABSTRACT

In this paper we examine the nexus between product markets and the legal system. 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 R&D 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 would choose. We consider two planners, one of whom is able to set safety standards, but takes the market equilibrium output as given, and one of whom can control both safety effort and output. We argue that the former type of planner is the better representative of what the tort system might do if faced with deciding upon a safety effort standard.

We examine two measures of competitiveness: the number of firms, and the degree of substitutability of the products. Holding 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 substitutability first decreases, but ultimately increases, the equilibrium safety effort. 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 over-provide safety effort. 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. Under-provision of safety becomes more typical as the rate of third-party exposure increases or as the amount of third-party uncompensated losses increases. Finally, we use the settlement subgame to examine the effects of alternative tort reform policies on the equilibrium provision of safety and welfare. In the presence of third-party victims, welfare can be increased even though changes in such policies may increase expected trial costs.

## 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 in research and development activity directed towards improving product safety depend on both market-provided incentives and incentives provided by the tort system. Attributes of the market 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. Attributes of the tort system that affect these decisions include the extent to which firms are held liable for the harms caused by their products, the costs associated with litigation, and the technology through which R&D investment affects the likelihood of injury and the extent of harm.

The topic of product safety has been addressed in both the industrial organization and law and economics literatures. The industrial organization literature considers the more general problem of 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 safety (quality) and output. In his model, strict liability on the part of the firm fully-insures consumers, and hence safety does not affect the slope of the demand curve. He finds that 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.<sup>1</sup>

The standard law and economics analysis (Shavell, 1980, 1987 and forthcoming) of the

market provision of safety under strict liability assumes that safety effort involves a constant expenditure per unit of output and that litigation is not costly.<sup>2</sup> 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 combine aspects of these two literatures to provide a more comprehensive model of how the market and the tort system interact to affect the equilibrium provision of safety. Like the industrial organization quality literature, we assume that there is a significant, endogenously-determined, fixed-cost component to safety effort, as would arise when safety can be improved through research and development, such as in automobiles and pharmaceuticals. In this case, the output and safety effort decisions are not separable. Like the law and economics literature, we will consider harms to both consumers and third parties, but we will modify that literature to include costly litigation. When litigation is costly victims will bear some of these costs, and consequently it will matter whether the victim is a consumer (who can attempt to shift these costs back to the firm by adjusting her willingness to pay for the product) or a third party (who has no such opportunity). 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. Finally, we consider a variety of imperfectly competitive market

structures and 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.

We first consider the victims-as-consumers (that is, two-party) model. We find that imperfectly competitive firms always provide too little output for any given level of safety effort. We examine two measures of competitiveness 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 (though the equilibrium safety effort for goods that are perfect substitutes is still lower than the monopoly level). An increase in a firm's safety effort has two effects: a direct effect (it lowers the firm's variable costs) and an indirect effect (it induces a reduction in rival firms' output). When the products are poor substitutes, the first effect dominates, while the second effect dominates when the products are good substitutes.

We compare equilibrium safety effort and output with two social benchmarks which vary in the extent to which the industry is controlled. A restricted social planner 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 planner thereby specifies the socially optimal level of safety much as a social-welfare maximizing court system would, since courts 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. 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. We also consider a less restricted social planner who can choose both safety effort and output. The comparison of equilibrium safety effort with the less restricted social planner's preferred level is qualitatively similar to the previous analysis, although there are minor quantitative differences. Thus this means that the market almost never provides the socially optimal level of safety (in contrast with the traditional argument), and there is a broad set of conditions under which it over- or under-produces safety.

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. We find that the market with third-party victims behaves in a qualitatively similar way with respect to our two measures of competitiveness. When we compare the equilibrium safety effort with what would be chosen by our two versions of a social planner, we find conditions under which greater substitutability is required to yield over-supply of safety effort in equilibrium. That is, the presence of third-party victims increases the set of parameters in which equilibrium safety effort will be inefficiently low.

Moreover, we show that even absent the fixed-cost distortion noted in the two-party case, the presence of litigation costs means that the safety level found by minimizing total production, harm and litigation costs will not be the level of safety provided by the market, nor will it be the socially optimal level of effort chosen by the restricted planner. This last point occurs because the presence of third parties bearing litigation losses again means that safety level and output level are interdependent for the restricted social planner (as was true in the analysis allowing for endogenously-generated fixed costs).

Finally, we delve into the details of the settlement subgame that generates the respective

costs borne by the firm and the injured parties. We consider how various policies, such as access control, damages caps, or evidentiary standards, shift the cost of harm between the victim and the injurer and affect the overall level of costs due to trial.<sup>3</sup> We find that changes in these policies that increase expected trial costs can, nevertheless, have beneficial effects upon social welfare.

### Plan of the Paper

In Section 2 we provide 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 two types of social planners and compares the socially optimal levels of safety effort and output with those 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 for the market and for the tort system. An Appendix provides much of the technical analysis.

## 2. Model Setup, Structure and Notation

### Preliminaries: Firms, Consumers and Social Planners

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. 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 (here flat fees) 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. 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 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.<sup>4</sup> Safety effort influences, but does not determine, the likelihood of a consumer being harmed by firm  $i$ 's product, denoted as  $\theta_i$ , and (if harmed) the monetary damages suffered, denoted as  $\delta_i$ . To capture this influence, we assume that  $\theta_i$  is distributed according to  $F(\theta; x_i)$  and  $\delta_i$  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 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 ( $\theta$  cannot be zero, no matter how large  $x$  is) and that any consumer who is harmed has a credible strategy 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).<sup>5</sup> 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  $\delta$ . Note that the expected value of  $L_D(\delta; x)$ ,  $EL_D(x) \equiv \int L_D(\delta; x)g(\delta; x)d\delta$ , is likely to depend upon the precise details of the bargaining game used to analyze settlement negotiations (in particular, who is the first mover); we delay this detailed examination until a later subsection, but note that  $EL_D(x)$  is likely to have properties (at least with respect to important parameters such as the cost of trial) qualitatively independent of the specified bargaining game form. Therefore, firm  $i$ 's expected loss from liability (per unit produced) is  $v(x_i) \equiv \hat{\theta}(x_i)EL_D(x_i)$ , where  $\hat{\theta}(x_i) \equiv \int \theta f(\theta; x_i)d\theta$ . 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,  $U(q_1, \dots, q_n) + q_{n+1}$ , where good  $n + 1$  is the numeraire

good, with its price equal to 1. In particular, we assume that  $U$  is quadratic in form, with parameters  $\alpha > 0$ ,  $\beta > 0$ , and  $\gamma$ :

$$U(q_1, \dots, q_n) = \sum_i \alpha q_i - \frac{1}{2} (\sum_i \beta q_i^2 + \sum_i \sum_{j \neq i} \gamma q_i q_j),$$

where  $\gamma$  is the degree of product substitution between any product, say  $i$ , and any other product.<sup>6</sup> We take  $\gamma$  to lie in the interval  $[0, \beta)$ , with perfect substitutes being the limit case when  $\gamma \rightarrow \beta$ . 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  $\gamma \rightarrow \beta$ ), then  $U(q_1, \dots, q_n) = \sum_i (\alpha q_i - \beta \sum_j q_i q_j/2)$ .

Consumers are rational and anticipate the effect of safety effort by each firm on the likelihood of harm as well the likely level of damages they will suffer.<sup>7</sup> As potential plaintiffs they know that if their realized damages are  $\delta$ , then settlement bargaining and possible litigation 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, should  $(\theta_i, \delta_i)$  be the realized outcome. Thus, our model of the consumer is to choose  $(q_1, \dots, q_n)$  so as to maximize their expected utility of consumption net of the expenditure on the  $n$  goods (the  $n+1$ st good is found as the residual):

$$\max_{\theta, \delta} E_{\theta, \delta} \{ U(q_1, \dots, q_n) + I - \sum_i [p_i + \theta_i L_p(\delta_i; x_i)] q_i \},$$

where  $I$  is the consumer's income. Denote the expected loss for any given  $x$  (given a harm has occurred) as  $EL_p(x) \equiv \int L_p(\delta; x) g(\delta; x) d\delta$ . This loss is the expected harm,  $\hat{\delta}(x) \equiv \int \delta g(\delta; x) d\delta$ , minus any transfer from the defendant due to settlement or trial, plus any court costs incurred should the case go to trial. Since  $\theta$  and  $\delta$  are independent (conditional on  $x$ ), the consumer's choice problem can be replaced by:

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

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:

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

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 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 harm 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  $n$ ,  $N$ ,  $x_i$ ,  $t$ ,  $q_i$ ,  $F$ ,  $G$ ,  $m(x)$ ,  $U(q_1, \dots, q_n)$ , 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. Thus, in this model there are three avenues along which competition among firms can be increased, namely through increases in  $x$ ,  $n$  and  $\gamma$ . There are also two avenues along which firms may be differentiated, namely through  $x$  and  $\gamma$ . We shall take  $n$  and  $\gamma$  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. 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 be interested in the welfare-maximizing levels of safety and output, and we will consider two possible types of social planner. Since our main purpose is to understand the interaction of product markets with the tort system, we will consider a social planner who can set the level of safety effort, but cannot control either the level of output or the number of firms. Another useful benchmark is captured by considering a social planner who can set both safety effort and quantity.<sup>8</sup> We refer to the first type of planner as a restricted social planner (RSP) and the second type as an unrestricted social planner (USP). In the RSP case the optimal safety effort level will be denoted  $X^{ra}$  and this will imply a (per customer) equilibrium level of output  $Q^{ra}$ . In the USP case, the optimal levels will be denoted  $X^n$  and  $Q^n$ . Thus, the use of capital letters is to remind the reader that the variables are being determined by a social welfare maximizer while the superscripts serve to remind the reader about which variables are taken as given (uncontrolled) by the planner.

#### Social and Private Safety and Production Costs

Thus,  $u(x) + v(x) = \hat{\theta}(x)[EL_p(x) + EL_D(x)] = \hat{\theta}(x)[\hat{\delta}(x) + ETC(x)]$  provides the 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 its assumed properties.<sup>9</sup>

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

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  $FMC_x(\bar{x}) = 0$ . In the sequel we further assume that all derivatives of FMC (with respect to  $x$  and any parameters) are bounded for  $x \in [0, \bar{x}]$ .

A Digression on Comparative Statics for the Analysis and the “Increasing Safety Effort Condition”

We will be especially interested in the effect of various parameters of our model on the market equilibrium, and the socially optimal, level of safety effort. In this subsection we provide the basic comparative statics results we will employ throughout the paper.

For purposes that will become clear in the sections to follow, we consider the following implicit function, which figures repeatedly in the first-order conditions for the safety effort level, and in the comparative statics analysis, in our results for firms and social planners:

$$H(x; a, b) \equiv -(\alpha - FMC(x; b))FMC_x(x; b) - a, \quad (*)$$

where  $a$  and  $b$  are non-negative parameters, and  $FMC_b > 0$ ; the derivatives of  $H$ ,  $H_x$  and  $H_b$ , are given in the Appendix. Note that the parameter “ $a$ ” above will typically appear as a function of a number of parameters of our model (e.g.,  $N$ ,  $t$ ,  $n$ ,  $\beta$ , and  $\gamma$ ), so that the actual effect of these model parameters on safety effort will be detailed as we proceed. For now, we restrict attention to  $a$  and  $b$ .

First, let us consider when there is a solution for equation (\*). Observe that, by Assumption 1,  $H(\bar{x}; a, b) = -a < 0$ . If  $H_x < 0$  for all  $x$  (and strict concavity of firm profits will imply this) and assuming that  $H(0; a, b) > 0$ , then there is always a unique solution, denoted  $x^*$ , to the equation  $H(x; a, b) = 0$ , which lies in the open interval  $(0, \bar{x})$ . Thus, since  $dx^*/da = 1/H_x < 0$ , parameters that influence  $a$  in a predictable manner (but do not influence FMC or  $\alpha$ ) thereby influence  $x^*$  in a similarly predictable manner (albeit with the opposite sign).

As indicated earlier, we assume that  $b$  is a parameter such that  $FMC_b > 0$ ; that is, increases in  $b$  increase the full marginal cost per unit of output produced. Since  $dx^*/db = -H_b/H_x$ , the sign of  $dx^*/db$  is the same as the sign of  $H_b$ . For example, a sufficient condition for  $dx^*/db < 0$  is that  $FMC_{xb} > 0$ , since  $FMC_{xb} > 0$  implies that  $H_b < 0$  (see the Appendix for details).

On the other hand, if  $FMC_{xb} < 0$ , then  $dx^*/db$  could be either positive or negative. As is discussed in the Appendix, when  $FMC_{xb} < 0$ , then  $dx^*/db > 0$  if and only if  $FMC_x/(\alpha - FMC) > FMC_{xb}/FMC_b$  at  $x^*$ . We emphasize this condition because it holds in some natural circumstances. In particular, if  $t$  is sufficiently small, or if  $N$  is sufficiently large, or if  $\alpha$  is sufficiently large, then  $FMC_x/(\alpha - FMC) > FMC_{xb}/FMC_b$ . Therefore, if demand is sufficiently high (at least in terms of  $\alpha$  or  $N$ ), or if the cost per unit of safety effort is sufficiently small, then this inequality will hold.

There is an intuitive sense to this condition that also makes it “focal.” Our interest is in safety, and harm occurs in our population of consumers (and, later, in third parties) both because of the level of safety effort and the volume of trade. Thus, if one considers the effect of a parameter which raises a firm’s marginal costs ( $FMC_b > 0$ ), but whose effect on those marginal costs can be mitigated by increasing safety effort ( $FMC_{xb} < 0$ ), then it seems plausible that  $dx^*/db > 0$ .

When the relevant inequality holds, we will say that the “increasing safety effort condition” (abbreviated as ISEC) holds for the parameter  $b$  under consideration.

**Definition 1.** The “increasing safety effort condition” (ISEC) holds for a  $b$ -parameter such that  $FMC_b > 0$  and  $FMC_{xb} < 0$ , when  $FMC_x/(\alpha - FMC) > FMC_{xb}/FMC_b$ , where all functions are evaluated at  $x^*$ .

Note that, in the sequel, we will suppress the  $b$ -parameter in  $FMC$  and  $H$  unless it is explicitly needed.

### 3. Market Provision of Safety and Output: The Two-Party Case

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

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

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 (R&D) costs, while the fourth term is the expected liability costs.<sup>10</sup> Substitution of elements from the previous section allow us to write firm  $i$ 's profit as:

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

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 quantities, the subgame-perfect equilibrium quantity levels will be functions of the safety effort levels, and therefore we will assume that the reduced-form profits (as functions of the safety effort levels) are concave in own safety effort. Note that it is immediate from the profit function above 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 a safety failure.<sup>11</sup>

#### Monopoly Provision

If there is only one firm in the industry, then we can write the firm's profits as:

$$\pi(x, q) = Nq[\alpha - \beta q - FMC(x)] - tx.$$

Conditions for an interior profit-maximizing solution,  $(x^1, q^1)$  are that:

$$\alpha - 2\beta q^1 - FMC(x^1) = 0; \tag{1}$$

$$-Nq^1 FMC_x(x^1) - t = 0. \tag{2}$$

Solving (1) yields  $q^1 = (\alpha - FMC(x^1))/2\beta$ . Substitution into (2) allows us to write this condition as  $H(x^1; a^1) = 0$ , where  $a^1 = 2\beta t/N$ . Since  $t > 0$ , this means that the optimal amount of safety effort does

not minimize  $FMC(x)$  and that  $x^1 < \bar{x}$ , the amount of safety effort that does minimize  $FMC(x)$ .

We make this observation because standard theory in law and economics (see, for example, Shavell, 1987, or Cooter and Ulen, 2000) provides the result that strict liability means that firms will choose the level of care that minimizes unit precaution costs plus unit expected losses from harm,  $FMC(x)$ . Obviously this doesn't hold here because we have included an endogenously-determined level of fixed costs ( $tx^1$ ) as part of the firm's cost function.<sup>12</sup>

Note also, from the comparative statics presentation at the end of Section 2, that  $dx^1/dt < 0$ ,  $dx^1/d\beta < 0$  and  $dx^1/dN > 0$ . In other words (and, for each, all else equal), more costly safety planning (i.e., increased  $t$ ) and lower individual willingness to pay (i.e., increased  $\beta$ ) both result in reductions in the level of safety effort chosen by the firm, while an increase in the aggregate number of consumers 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 (2) above as:

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

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 above is the impact on items which are purely cost effects: the direct safety effort cost,  $tx^1$ , production costs,  $Nq_1m(x^1)$ , and direct expected liability costs,  $Nq_1v(x^1)$ . 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:



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

As indicated at the beginning of Section 2, we assume that all  $n$  firms (simultaneously and non-cooperatively) choose individual levels of safety effort,  $x_i$ ,  $i = 1, \dots, n$ , which then become common knowledge for all, and then the  $n$  firms (simultaneously and non-cooperatively) choose their output levels,  $q_i$ ,  $i = 1, \dots, n$ . 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:

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

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

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

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) is:

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

We can re-write (5) as  $\{- Nq_i^n FMC_x(x_i) - t\} + \{Nq_i^n \gamma \sum_{j \neq i} [- \partial q_j^n / \partial x_i]\} = 0$ . Note that the first term in braces is similar to (2), 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 "direct 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 (2); 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  $q_i^n$  above (i.e., equation (4)), it is clear that  $[- \partial q_j^n / \partial x_i] = - \gamma FMC_x(x_i) / [(2\beta - \gamma)(2\beta + (n-1)\gamma)] > 0$ , so that the term in the second set

of braces is positive. This “indirect effect” on marginal profits is a spillover from the presence of the other firms: if firm  $i$  increases  $x_i$ , all the other firms (in equilibrium, and all else equal) decrease their equilibrium output levels, shifting demand in the direction of firm  $i$  by the amount shown in the braces.<sup>13</sup> Differentiating the two terms (the direct effect and the indirect effect) with respect to  $\gamma$  shows that the derivative of the first effect is negative but diminishing in  $\gamma$  while the indirect effect (which is initially zero when  $\gamma$  is zero) is increasing in  $\gamma$ . We shall return to this result below when we consider the symmetric safety effort equilibrium.

#### Symmetric Safety Effort in Oligopoly Equilibrium

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

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

and the equilibrium  $x^n$  is given implicitly by:

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

If we let  $a^n = (t/N)(2\beta - \gamma)(2\beta + (n-1)\gamma)^2/[(2\beta - \gamma)(2\beta + (n-1)\gamma) + \gamma^2(n-1)]$ , then (7) can be rewritten as  $H(x^n; a^n) = 0$ . Recall (see Section 2) that  $dx^*/da = 1/H_x$  and that  $H_x < 0$ .<sup>14</sup> Thus, if we think of  $y$  as being  $t$ ,  $N$ ,  $\beta$ ,  $\gamma$ , or  $n$ , then  $dx^n/dy = (1/H_x)(\partial a^n/\partial y)$ , so that  $\text{sign}(dx^n/dy) = -\text{sign}(\partial a^n/\partial y)$ . While gruesome, these can be computed and we find that:  $dx^n/dt < 0$ ,  $dx^n/dN > 0$ ,  $dx^n/d\beta < 0$ , and  $dx^n/dn < 0$ . The first three effects are the same (in sign) as in the monopoly case; the fourth effect arises due to the presence of other firms. This means that the greater the intensity of competition (measured by the number of firms,  $n$ ) 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  $\gamma$ , a different measure of the intensity of competition; this effect is not monotonic. The effect of  $\gamma$

on  $x^n$  is first negative, but eventually positive:  $dx^n/d\gamma > 0$  as  $\gamma > \gamma^{\min}(\beta, n)$ , where  $\gamma^{\min}(\beta, n) = 2\beta/3$  for  $n = 2$ , and  $\gamma^{\min}(\beta, n) = \beta[n - 5 + (n^2 - 2n + 9)^{1/2}]/2(n-2)$  for  $n > 2$ . Figure 1 below illustrates the effect of  $\gamma$  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  $\gamma$  increases, reaches a minimum at  $\gamma^{\min}(\beta, n)$ , and then increases as  $\gamma$  continues to increase. It is straightforward to show that: i)  $\partial\gamma^{\min}(\beta, n)/\partial n > 0$  and ii)  $\lim_{n \rightarrow \infty} \gamma^{\min}(\beta, n) = \beta$ . Thus, our two ways of thinking about increases in competition have both positively- and negatively-correlated effects on the equilibrium

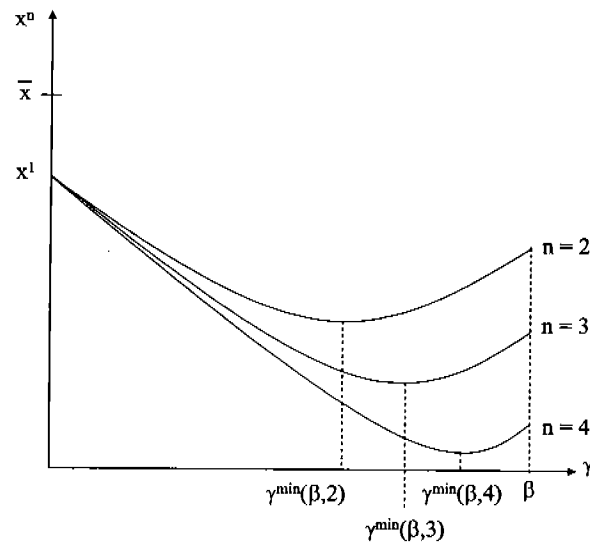


Figure 1: Behavior of Safety Effort ( $x^n$ ) as a function of  $\gamma$  and  $n$

safety level. Initially, as either  $n$  or  $\gamma$  increases from the monopoly setting, competition drives  $x^n$  down. However, once  $\gamma$  becomes large enough (above  $\gamma^{\min}$ ), increases in the substitutability of the products actually leads to increases in the equilibrium safety level. The reason for this comes from

our earlier discussion of direct and indirect effects of safety effort on profit: direct effects (derived from changes in FMC) predominate when  $\gamma$  is low, but diminish as  $\gamma$  grows, while the indirect effects (reflecting the effect of  $x_i$  on competitors' outputs) grow as  $\gamma$  grows, eventually reversing the sign of  $dx^n/d\gamma$  (i.e., making it positive). Note further that (as indicated in Figure 1)  $x^n(\gamma) < x^1$  for all  $0 < \gamma \leq \beta$  and that  $x^n(\gamma) > x^{n+1}(\gamma)$  for all  $0 < \gamma \leq \beta$ . For convenience, we summarize the results of the symmetric equilibrium in Proposition 1 below.<sup>15</sup>

**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

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

ii) safety effort at each firm,  $x^n$ , is defined (implicitly) by

$$-Nq^n(x^n)\text{FMC}_x(x^n)\{1 + \gamma^2(n-1)/[(2\beta - \gamma)(2\beta + (n-1)\gamma)]\} - t = 0,$$

and is increasing in  $N$  and  $\gamma$  (for  $\gamma > \gamma^{\min}$ ), and decreasing in  $t$ ,  $\beta$ ,  $n$ , and  $\gamma$  (for  $\gamma < \gamma^{\min}$ ).

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

#### 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 problems faced by two alternative planners: the restricted social planner (RSP) and the unrestricted social planner (USP). Neither planner can control the number of firms, but RSP chooses the level of safety, taking the firms' non-cooperative equilibrium choices for output (conditional on safety level) as given, while USP chooses the levels of both safety and output.

The objective of both RSP and USP is to maximize social welfare, allowing for  $n$  firms and maintaining strict liability for harm. Thus, RSP's problem is:

$$\max_x \{NU(Q_1, \dots, Q_n) - \sum_i [NQ_i FMC(X_i) + tX_i] \mid Q_i = q^n(X_1, \dots, X_n), i = 1, \dots, n\} \quad (8)$$

while USP's problem is:

$$\max_{x,Q} NU(Q_1, \dots, Q_n) - \sum_i [NQ_i FMC(X_i) + tX_i]. \quad (9)$$

In what follows we restrict attention to the symmetric solution. Let  $(X^{nq}, Q^{nq})$  solve RSP's problem and let  $(X^n, Q^n)$  solve USP's problem. The first-order conditions for an interior solution for RSP for  $Q^{nq}$  and  $X^{nq}$ , respectively, are:

$$\alpha - (2\beta + (n-1)\gamma)Q^{nq} - FMC(X^{nq}) = 0; \quad (10)$$

$$-NQ^{nq}FMC_x(X^{nq}) - t[(2\beta + (n-1)\gamma)/(3\beta + (n-1)\gamma)] = 0. \quad (11)$$

The first-order conditions for an interior solution for USP for  $Q^n$  and  $X^n$ , respectively, are:

$$\alpha - (\beta + (n-1)\gamma)Q^n - FMC(X^n) = 0; \quad (12)$$

$$-NQ^nFMC_x(X^n) - t = 0. \quad (13)$$

Solving (10) and (12), we see that:

$$Q^{nq} = (\alpha - FMC(X^{nq})) / (2\beta + (n-1)\gamma); \quad (14)$$

$$Q^n = (\alpha - FMC(X^n)) / (\beta + (n-1)\gamma), \quad (15)$$

while (11) and (13) can be written as (see Section 2 above):

$$H(X^{nq}; A^{nq}) = 0, \text{ where } A^{nq} = (t/N)(2\beta + (n-1)\gamma)^2 / (3\beta + (n-1)\gamma); \quad (16)$$

$$H(X^n; A^n) = 0, \text{ where } A^n = (t/N)(\beta + (n-1)\gamma). \quad (17)$$

Note that, for each  $(\gamma, n)$ ,  $A^{nq} > A^n$ , which means that USP chooses a higher level of safety effort than does RSP:  $X^n > X^{nq}$ . Moreover, since both  $A^n$  and  $A^{nq}$  are monotonically increasing in  $\gamma$  and in  $n$ , both  $X^n$  and  $X^{nq}$  are monotonically decreasing in  $\gamma$  and in  $n$  (for  $\gamma > 0$ ). Finally, from the definitions of  $A^n$  and  $A^{nq}$  it is evident that  $X^n$  and  $X^{nq}$  are both increasing in  $N$  and decreasing in  $t$  and  $\beta$ .

Comparisons Between the Restricted Planner's Choices and the Equilibrium Oligopoly Outcomes

First, we compare  $x^n$  with  $X^{nq}$  and  $q^n$  with  $Q^{nq}$ . By definition, for any fixed level of safety effort,  $Q^{nq}(x) = q^n(x)$ . Thus, the 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  $x^n \gtrless X^{nq}$ . To see how  $x^n$  and  $X^{nq}$  compare, we compare  $a^n$  with  $A^{nq}$ . The properties of  $H$  imply that  $x^n \gtrless X^{nq}$  if and only if  $A^{nq} \gtrless a^n$ . In this case, for  $n \geq 2$ ,  $A^{nq} \gtrless a^n$  as  $\gamma \gtrless \Gamma^{nq}(\beta, n)$ , where  $\Gamma^{nq}(\beta, n)$  equates  $A^{nq}$  to  $a^n$ .  $\Gamma^{nq}(\beta, n)$  provides the value of  $\gamma$  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. In this case,  $\Gamma^{nq}(\beta, n) \equiv \beta([\delta n - 7]^{1/2} - 1)/(2(n-1))$ . Note that  $\Gamma^{nq}(\beta, 2) = \beta$ , so that the socially optimal level of safety effort exceeds that provided by a duopoly except when the goods are homogeneous, in which case the duopolists provide exactly the socially optimal level of effort. However, when  $n > 2$ , then  $\Gamma^{nq}(\beta, n) < \beta$ , so that there is a set of  $\gamma$ -values such that the oligopoly over-supplies safety. Also, since  $\partial \Gamma^{nq}(\beta, n)/\partial n < 0$ , the set of  $\gamma$ -values where  $x^n$  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 socially optimal level.

Comparisons Between the Unrestricted Planner's Choices and the Equilibrium Oligopoly Outcomes

Similarly, let us compare  $x^n$  and  $q^n$  with  $X^n$  and  $Q^n$ . Comparing (15) and (6), it is immediately clear that, for any fixed level of safety effort,  $q^n(x) < Q^n(x)$ . Comparing the solutions to (7) and (17) amounts to comparing  $a^n$  and  $A^n$ . Once again, from the properties of  $H$  we know that  $x^n \gtrless X^n$  if and only if  $A^n \gtrless a^n$ . Some tedious algebra shows that, when  $n = 2$ ,  $A^n < a^n$  for all values of  $\gamma$ , and thus that

$X^n > x^n$  for all values of  $\gamma$  when  $n = 2$ . However, for  $n \geq 3$ ,  $A^n > a^n$  as  $\gamma > \Gamma^n(\beta, n)$ , where  $\Gamma^n(\beta, n)$  equates  $A^n$  and  $a^n$ .  $\Gamma^n(\beta, n)$  provides the value of  $\gamma$  wherein the function describing  $X^n$  just crosses that for  $x^n$ ; at this point, the equilibrium safety effort produced by the  $n$ -firm oligopoly is the same as the unrestricted social planner would have chosen. It can be shown that there is a unique  $\Gamma^n(\beta, n) \in (0, \beta)$  for all  $n > 2$  and that  $\partial\Gamma^n(\beta, n)/\partial n < 0$ . Thus, a result similar to that under RSP holds: the set of  $\gamma$ -values where  $x^n$  exceeds  $X^n$  increases as  $n$  increases.

### Summary of Welfare Results

Our results are illustrated in Figure 2 below (the restricted planner's solution is illustrated on the left); note that, while illustrated as convex, the solid curves for  $X^{nq}$  and  $X^n$  need not be convex, just monotonically decreasing. We summarize the analysis of RSP and USP, and the comparisons with the market equilibrium outcomes, in Proposition 2.

#### Proposition 2.

- i) For any given  $(\gamma, n)$ , the restricted planner chooses a lower level of safety than the unrestricted planner:  $X^n > X^{nq}$ . Moreover,  $X^n$  and  $X^{nq}$  are both decreasing in  $\beta$ ,  $\gamma$  and  $n$  (for  $\gamma > 0$ ), and increasing in  $N$ .
- ii) With respect to the restricted planner's level of safety, firms in market equilibrium under-supply safety (and output) if and only if  $\gamma < \Gamma^{nq}(\beta, n)$ ; otherwise they over-supply safety (and output).  $\Gamma^{nq}(\beta, 2) = \beta$ ,  $\Gamma^{nq}(\beta, n) \in (0, \beta)$  for all  $n > 2$  and  $\partial\Gamma^{nq}(\beta, n)/\partial n < 0$ .
- iii) With respect to the unrestricted planner's level of safety, firms in market equilibrium under-supply safety if and only if  $\gamma < \Gamma^n(\beta, n)$ ; otherwise they over-supply safety.  $\Gamma^n(\beta, n) \in (0, \beta)$  for all  $n > 2$  and  $\partial\Gamma^n(\beta, n)/\partial n < 0$ . Moreover, when firms under-supply safety they under-supply output as well.

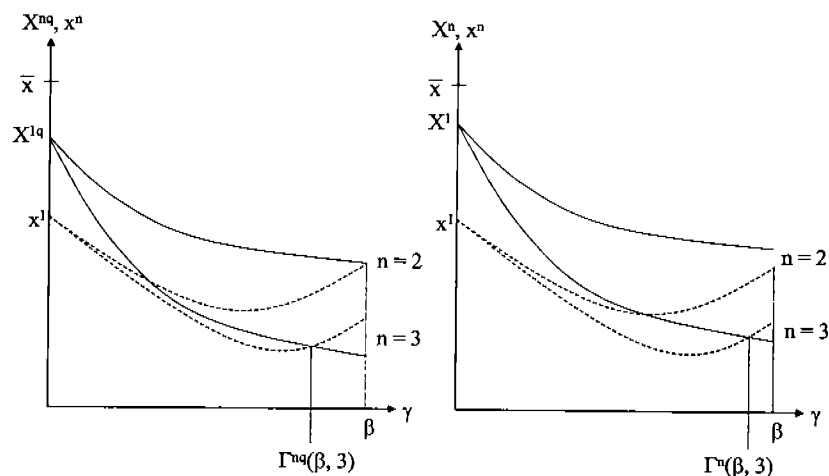


Figure 2: Socially Optimal Provision of Safety in Comparison with the Equilibrium Provision

## 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 customers of a firm leads to harms suffered by non-customers. To simplify matters, we again focus on the symmetric solution (in safety effort and quantities) and we assume that bilateral precaution (in particular, by each firm's customers) is not possible. Thus, for example, in the well-known Pinto case (see Viscusi, 1991, for details), 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 this 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  $\phi$  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  $\phi Nq_i$ . Let the expected per-unit loss for a non-consumer associated with harms from firm  $i$ 's product be denoted  $\tilde{u}(x_i)$ . Note that this implicitly allows us to employ alternative distributions,  $\tilde{F}$  and  $\tilde{G}$ , for the likelihood of harm occurring and for the consequent likely damages; we assume that they have properties similar to  $F$  and  $G$  stated earlier. Thus, we expect  $\tilde{u}_x(\bullet) < 0$  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 loss arising from harms to a non-consumer, with  $\tilde{v}_x(\bullet) < 0$  and  $\tilde{v}_{xx}(\bullet) > 0$ .

This means that the *ex ante* expected damages plus court costs imposed on non-consumers and firm  $i$  are  $\phi Nq_i(\tilde{u}(x_i) + \tilde{v}(x_i))$ . Note, however, that unlike the two-party case, the firm does not face the non-consumer loss,  $\phi Nq_i\tilde{u}(x_i)$ , since only product consumers are able to reduce their willingness to pay in anticipation of uncompensated losses. Thus, profits for firm  $i$  are:

$$\pi_i(x_i, q_1, \dots, q_n) = Nq_i[\alpha - u(x_i) - \beta q_i - \gamma \sum_{j \neq i} q_j - m(x_i) - v(x_i)] - \phi Nq_i\tilde{v}(x_i) - tx_i.$$

Let  $FMC^f(x_i) \equiv FMC(x_i) + \phi\tilde{v}(x_i)$ . Then we can write firm  $i$ 's profits as:

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

A comparison with the profit function specified in Section 3 earlier indicates that they are of the same form and therefore the equilibrium safety effort and output levels will behave in a similar manner with respect to parameters such as  $n$ ,  $\beta$ ,  $\gamma$ ,  $t$ , and  $N$ .

Note, however, 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  $FMC_x^f(\bar{x}^f) = 0$  and let  $\bar{x}^S$  be such that  $FMC_x^S(\bar{x}^S) = 0$ ; 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 USP would choose in the three-party case. Finally, we further assume that the properties of FMC carry over to  $FMC^f$  and  $FMC^S$ .

#### Market Equilibrium and Comparative Statics: $t > 0$

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) above, with  $q^n(x^n)$  given by:

$$q^n(x^n) = (\alpha - FMC^f(x^n)) / (2\beta + (n-1)\gamma), \quad (18)$$

and the equilibrium  $x^n$  given implicitly by:

$$-Nq^n(x^n)FMC_x^f(x^n) \{1 + \gamma^2(n-1) / [(2\beta - \gamma)(2\beta + (n-1)\gamma)]\} - t = 0. \quad (19)$$

This structurally-familiar form means that, once again,  $dx^n/dt < 0$ ,  $dx^n/dN > 0$ ,  $dx^n/d\beta < 0$ , and  $dx^n/dn < 0$ . Further, since  $\gamma^{\min}$ , the turning point for each of the curves displayed in Figure 1 above, is a function only of  $\beta$  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  $\gamma$ , so  $dx^n/d\gamma < 0$  when  $\gamma < \gamma^{\min}$ , while  $dx^n/d\gamma > 0$  when  $\gamma > \gamma^{\min}$ .

Note that changes in  $\phi$  influence  $FMC^f$  directly (as we shall see in a later section, other parameters, such as those in the settlement subgame, also affect  $FMC^f$ ). In other words,  $\phi$  is a

“b-parameter” as discussed in Section 2 above. Let:

$$H^f(x; a, b) \equiv -(\alpha - FMC^f(x; b))FMC_x^f(x; b) - a.$$

In particular,  $H^f(x^n; a^n, b) = 0$ .<sup>16</sup> Observe that parameters such as  $n$ ,  $\beta$ ,  $\gamma$ ,  $N$  and  $t$  affect the “a”-term above, while parameters that influence  $u$ ,  $v$ ,  $\tilde{v}$ ,  $m$ , as well as the parameter  $\phi$ , affect the “b”-term above. As shown in the Appendix,  $H_x^f(x^n; a^n, b) < 0$  due to the second-order condition for firm  $i$ 's profit maximization problem. Differentiating  $H^f(x^n; a^n, b)$  with respect to  $b$  yields:

$$H_b^f(x^n; a^n, b) = -(\alpha - FMC^f(x^n; b))FMC_{xb}^f(x^n; b) + FMC_x^f(x^n; b)FMC_b^f(x^n; b).$$

Since  $dx^n/db = -H_b^f/H_x^f$ , the sign of  $dx^n/db$  is the same as the sign of  $H_b^f$ . We use the results from Section 2 (the “increasing safety effort condition”, or ISEC, in Definition 1, as modified by using  $FMC^f$ ) and the discussion from the Appendix in what follows.

From the definition of  $FMC^f(x; b)$ , it is immediate that  $FMC_{x\phi}^f(x; \phi) = \tilde{v}_x(x) < 0$ , so  $dx^n/d\phi > 0$  under ISEC. In other words, if the effect of an increase on safety effort on the firm's expected loss due to settlement and litigation with non-consumers is sufficiently strong, then an increase in the non-consumers' exposure rate,  $\phi$ , induces an increased equilibrium investment in safety effort. Thus, even though there is no direct effect on the firms via the market (as there is for consumers of the product via the willingness to pay), transfers to non-consumers and inefficiencies inherent in the settlement and litigation process provide a “feedback loop” (under ISEC) that encourages greater safety effort in response to increased negative spillovers on non-consumers.

We can also explore comparative statics results for  $q^n$ . Equation (18) implies that:

$$dq^n/dy = -[FMC_x^f(x^n)/(2\beta + (n-1)\gamma)](dx^n/dy) - [q^n/(2\beta + (n-1)\gamma)](d(2\beta + (n-1)\gamma)/dy)$$

where  $y = N$ ,  $n$ ,  $\beta$  or  $\gamma$ . Thus,

$$dq^n/dN = [-FMC_x^f(x^n)/(2\beta + (n-1)\gamma)](dx^n/dN);$$

$$dq^n/dn = [-FMC_x^f(x^n)/(2\beta + (n-1)\gamma)](dx^n/dn) - \gamma q^n/(2\beta + (n-1)\gamma);$$

$$dq^n/d\beta = [-FMC_x^f(x^n)/(2\beta + (n-1)\gamma)](dx^n/d\beta) - 2q^n/(2\beta + (n-1)\gamma);$$

$$dq^n/d\gamma = [-FMC_x^f(x^n)/(2\beta + (n-1)\gamma)](dx^n/d\gamma) - (n-1)q^n/(2\beta + (n-1)\gamma).$$

For  $dq^n/dN$ , the term in square brackets is positive; since  $dx^n/dN > 0$ , so is  $dq^n/dN$ . Similarly, since  $dx^n/dn < 0$  and  $dx^n/d\beta < 0$ , so are  $dq^n/dn$  and  $dq^n/d\beta$ . Finally, when  $dx^n/d\gamma < 0$ , so is  $dq^n/d\gamma$ , but the effect of an increase in  $\gamma$  on  $q^n$  is unclear when  $dx^n/d\gamma > 0$ . If  $dx^n/d\gamma$  is sufficiently small, then  $dq^n/d\gamma < 0$ . However, if  $dx^n/d\gamma$  is sufficiently large (which might occur if  $\gamma$  is sufficiently far above  $\gamma^{\min}$ ), then  $dq^n/d\gamma$  could become positive.

Since  $\phi$  influences  $FMC^f$  directly and via its effect on  $x^n$ , then differentiating (18) yields:

$$dq^n/d\phi = - [FMC_\phi^f(x^n; \phi) + (dx^n/d\phi)FMC_x^f(x^n; \phi)]/(2\beta + (n-1)\gamma).$$

Since  $FMC_\phi^f(x; \phi) = \tilde{v}(x) > 0$ , if  $dx^n/d\phi < 0$ , then so is  $dq^n/d\phi$ . In other words, when the exposure rate for non-consumers increases, if firms respond by cutting the level of safety effort, they will also reduce the level of output in equilibrium. Essentially, they are withdrawing from the market.

The effect on  $q^n$  of an increase in  $\phi$  is more complex if  $dx^n/d\phi > 0$ ; that is, if ISEC is met. Using the results from the Appendix,

$$dq^n/d\phi < 0 \text{ if and only if } \tilde{v}_x(x^n)/\tilde{v}(x^n) > FMC_{xx}^f(x^n; \phi)/FMC_x^f(x^n; \phi). \quad (20)$$

As discussed in the Appendix, the second inequality in (20) holds for  $t$  sufficiently small, or  $N$  and/or  $\alpha$  sufficiently large.

**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

$$q^n(x^n) = (\alpha - FMC^f(x^n))/(2\beta + (n-1)\gamma);$$

ii) safety effort at each firm,  $x^n$ , is defined (implicitly) by

$$- Nq^n(x^n)FMC_x^f(x^n)\{1 + \gamma^2(n-1)/[(2\beta - \gamma)(2\beta + (n-1)\gamma)]\} - t = 0,$$

and is increasing in  $N$  and  $\gamma$  (for  $\gamma > \gamma^{\min}$ ), and decreasing in  $t$ ,  $\beta$ ,  $n$ , and  $\gamma$  (for  $\gamma < \gamma^{\min}$ ).

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

iii) Per-unit cost-minimizing safety effort (that is, at  $t = 0$ ) increases relative to the two-party case: when  $\phi > 0$ ,  $\bar{x} < \bar{x}^f$ .

iv)  $dx^n/d\phi > 0$  if and only if  $FMC_x^f(x^n)/(\alpha - FMC^f(x^n)) > \tilde{v}_x(x^n)/\tilde{v}(x^n)$  (i.e., ISEC holds). If  $dx^n/d\phi > 0$ , then  $dq^n/d\phi < 0$  if and only if  $\tilde{v}_x(x^n)/\tilde{v}(x^n) > FMC_{xx}^f(x^n)/FMC_x^f(x^n)$ . Sufficient, but not necessary, conditions for these to hold are that  $t$  is sufficiently small,  $N$  is sufficiently large or  $\alpha$  is sufficiently large.

(v) If  $dx^n/d\phi < 0$  then  $dq^n/d\phi < 0$ .

#### Market Equilibrium and Social Optimality in the Three-Party Case when $t = 0$

The conditions for social optimality (under RSP and USP) when  $t > 0$  are quite complex; we provide them, and a comparison with the foregoing market equilibrium, in the Appendix. The complexity of these results motivates examining the case when  $t = 0$ . This would seem to return us to the more traditional results, wherein both the private and social computations were based on per-unit (of output) production and liability-related costs. However, the presence of third parties, in conjunction with private information at the settlement stage, means that the choice of safety effort and output level is still intertwined for RSP, and will still mean that the market and the planner will generally not choose the same levels of safety effort (this is true for RSP as well as USP).

First, we re-examine the conditions for market equilibrium, displayed earlier as equations (18) and (19). If  $t = 0$ , then these become:

$$q^n(x^n) = (\alpha - FMC^f(x^n))/(2\beta + (n-1)\gamma); \quad (21)$$

$$- Nq^n(x^n)FMC_x^f(x^n) = 0. \quad (22)$$

Therefore, it is immediate that  $x^n = \bar{x}^f$ .

Under the assumption that  $t = 0$ , RSP's optimization problem becomes:

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

Therefore, the following conditions characterize  $Q^{nq}$  and  $X^{nq}$  for this case:

$$Q^{nq} = (\alpha - FMC^f(X^{nq})) / (2\beta + (n-1)\gamma); \quad (23)$$

$$- (\alpha - FMC^f(X^{nq}))FMC_x^f(X^{nq}) + \phi [(2\beta + (n-1)\gamma) / (3\beta + (n-1)\gamma)] [\tilde{u}(X^{nq})FMC_x^f(X^{nq}) - \tilde{u}_x(X^{nq})(\alpha - FMC^f(X^{nq}))] = 0. \quad (24)$$

If (24) is evaluated at  $\bar{x}^f$ , then 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  $\gamma$  and  $n$ .<sup>17</sup>

Moreover, this means that  $FMC_x^f(X^{nq}) > 0$ . That is, RSP would prefer the firm to operate on the upward-sloping portion of  $FMC^f$ .

Under the assumption that  $t = 0$ , USP's optimization problem becomes:

$$\max_{x,Q} N[n(\alpha Q - \beta Q^2/2 - (n-1)\gamma Q^2/2) - nFMC^S(X)Q],$$

and, thus, the following conditions characterize  $Q^n$  and  $X^n$  for this case:

$$Q^n = (\alpha - FMC^S(X^n)) / (\beta + (n-1)\gamma); \quad (25)$$

$$- (\alpha - FMC^S(X^n))FMC_x^S(X^n) = 0. \quad (26)$$

In this case,  $X^n = \bar{x}^S$ , but since  $\bar{x}^f < \bar{x}^S$ , this means that  $x^n < X^n$ . Hence, from the perspective of USP, the market under-supplies safety effort.

More significantly, there are conditions such that  $X^{nq} > X^n$ . This is important because, to the degree that RSP's choices resemble the decisions of courts determining whether "sufficient" safety effort was employed, employment of tort law (which generally is mute on the question of whether

a defendant produced an appropriate level of output) may lead to standard setting that is greater than that which USP would have chosen, something that will never occur in the two-party case.

To see when  $X^{nq} > X^n$ , re-consider the first-order-condition in RSP's problem when  $t = 0$ . The condition for the safety effort level can be written as:

$$-Q^{nq}(x)FMC_x^s(x) - (\beta Q^{nq}(x) - \phi \tilde{u}(x))FMC_x^f(x)/(2\beta + (n-1)\gamma) = 0.$$

At  $x = \bar{x}^s$ ,  $FMC_x^s(x) = 0$  and  $FMC_x^f(x) > 0$ . Then, the above first-order-condition, evaluated at  $\bar{x}^s$ , is positive if  $\beta Q^{nq}(\bar{x}^s) < \phi \tilde{u}(\bar{x}^s)$ . Thus,  $X^{nq} > \bar{x}^s = X^n$  if and only if  $\beta Q^{nq}(\bar{x}^s) < \phi \tilde{u}(\bar{x}^s)$ . This condition clearly fails when  $\phi = 0$ . However, consider  $\phi$  positive and fixed and assume that  $\beta Q^{nq}(\bar{x}^s) > \phi \tilde{u}(\bar{x}^s)$ . Notice that  $Q^{nq}(\bar{x}^s)$  is a monotonically decreasing function of  $n$ , while  $\phi \tilde{u}(\bar{x}^s)$  is independent of  $n$ . Thus, for any given  $\phi$ , there always exists an  $n$  such that  $\beta Q^{nq}(\bar{x}^s) < \phi \tilde{u}(\bar{x}^s)$ . This result is summarized in Proposition 4.

**Proposition 4.** If  $t = 0$  and  $\phi > 0$ , then there exists an  $n^*$  (dependent upon  $\phi$ ) such that:

$$n > n^* \Rightarrow X^{nq} > X^n.$$

This proposition once again reflects the interdependence of safety effort and quantity, in this case because of the presence of third parties. Since courts don't instruct firms to adjust their output (i.e., force them to adhere to  $Q^n$  instead of  $q^n$ ), the RSP solution is to increase safety effort, certainly above what the firms would choose, and possibly above what USP would choose. Alternatively put, USP sets the optimal level of safety effort too low when industries are sufficiently large.

It seems somewhat odd that RSP would prefer a level of safety effort that exceeds  $\bar{x}^s$ . However, this can be understood if we make the following observations. First, a non-cooperative firm has an incentive to produce less output than USP would prefer, as seen by comparing the denominators of  $q^n(x)$  and  $Q^n(x)$ ; this reflects the oligopoly incentives to restrict output. On the other

hand, a non-cooperative firm has an incentive to produce more than USP would choose, since the firm faces  $FMC^f$ , not  $FMC^S$ ; that is, the firm does not face the full social costs. Thus, just as it is possible for  $X^{nq}$  to exceed  $X^n$ , it is possible for  $Q^{nq}$  (or, equivalently,  $q^n$ ) to exceed  $Q^n$ . Indeed, it can be shown that  $\beta Q^{nq}(\bar{x}^S) < \phi \tilde{u}(\bar{x}^S)$  (and hence,  $X^{nq} > \bar{x}^S = X^n$ ) if and only if  $Q^{nq}(\bar{x}^S) > Q^n(\bar{x}^S)$ . In this case, non-cooperative firms would produce too much output, and thus RSP raises  $X^{nq}$  beyond  $\bar{x}^S$  in order to raise  $FMC^f$  (which is increasing in  $x$  at  $\bar{x}^S$ ) and thereby induce the non-cooperative firms to reduce their output, which reduces uncompensated losses to third parties.

#### 6. Implications of Tort Reform for the Market Equilibrium Safety Effort and Quantity

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 therefore 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 plaintiff and defendant ( $K$ ), the likelihood of  $P$  winning at trial (denoted as  $\sigma$ ) and the maximum allowed compensation (denoted as  $\delta^{\max}$ ). These parameters reflect access to courts (higher  $K$  means litigation is more costly and therefore access is more difficult), the evidentiary standard employed to find  $D$  liable (lower  $\sigma$  is associated with a higher evidentiary standard, making it less likely that  $P$  will win) and “caps” on compensation (lower  $\delta^{\max}$  is associated with tighter caps on compensation, meaning that the expected award at trial is lower). Interestingly, there are conditions under which increasing expected trial costs (via increases in  $K$ ,  $\sigma$ , or  $\delta^{\max}$ ) makes overall welfare increase.



It is traditional in this literature<sup>18</sup> to consider two possible forms for the one-sided incomplete information settlement bargaining game, one wherein P moves first and one wherein D moves first.<sup>19</sup> As described above, the game with P as first mover is a signaling game (since P has private knowledge of the level of damages,  $\delta$ ) while the game with D as first mover is a screening game (since D is uninformed about the actual level of damages).<sup>20</sup> In such games trials occur with positive probability due to the presence of private information which cannot be verified in a costless manner.

The Appendix provides details on a signaling game where, for concreteness, we have assumed that D's prior on P's damages,  $G(\delta; x)$ , is a negative exponential distribution on a constant support  $[\underline{\delta}, \infty)$  with parameter  $\mu(x)$ ; we employ a signaling model because it provides sufficient structure to sign the relevant derivatives.<sup>21</sup> The previously-assumed properties of  $G$  with respect to  $x$  (i.e., FOSD) imply that  $\mu_x(\bullet) > 0$ ; we also assume that  $\mu_{xx}(\bullet) < 0$  (these are sufficient conditions to make expected damages decreasing and convex in  $x$ ). As indicated in the Appendix, we also assume that  $\sigma \underline{\delta} > k_p$  (trial is a credible threat for P),  $\delta^{\max} > \hat{\delta}(x)$  (the cap is not so severe as to restrict compensation below the average harm), and some technical assumptions to assure that  $EL_p > 0$  (that potential plaintiffs cannot profit by being harmed) and that increases in court costs are not borne by one party alone.

The Appendix provides the equations for  $ETC(x; K, \sigma, \delta^{\max})$ ,  $EL_p(x; K, \sigma, \delta^{\max})$ , and  $EL_D(x; K, \sigma, \delta^{\max})$ . These are then employed to generate signs for the derivatives of FMC with respect to  $x$ , and the parameters. Proposition 5 summarizes the relevant results from the Appendix.

Proposition 5.

a) In the two-party case:

i)  $FMC_K > 0$  and  $FMC_{xK} < 0$ ;

ii)  $FMC_\sigma > 0$  and  $FMC_{x\sigma} < 0$  ( $> 0$ ) as  $\hat{\theta}_x ETC_\sigma + \hat{\theta} ETC_{x\sigma} < 0$  ( $> 0$ );

and iii)  $FMC_{\delta}^{f, \max} > 0$  and  $FMC_{x\delta}^{f, \max} < 0$ .

b) In the three-party case:

i)  $FMC_K^f > 0$  and  $FMC_{xK}^f < 0$ ;

ii)  $FMC_{\sigma}^f > 0$  and [ $FMC_{x\sigma}^f < 0$  if  $FMC_{x\sigma} < 0$ ];

and iii)  $FMC_{\delta}^{f, \max} > 0$  and  $FMC_{x\delta}^{f, \max} < 0$ .

### Discussion

We first discuss the impact of changes in the three parameters of interest on safety effort and then examine when such increases in safety effort are welfare-enhancing. We find that raising the expected costs of trial may increase welfare rather than decrease it.

First, consider the two-party case. Increasing trial costs,  $K$ , increases (see the Appendix) the expected trial costs ( $ETC_K > 0$ ) and the expected losses for each litigant ( $EL_{PK} > 0$  and  $EL_{DK} > 0$ ). It is not surprising that  $FMC_K > 0$  (see Proposition 5). However, note that increasing safety effort ameliorates this effect ( $FMC_{xK} < 0$ ). So, when ISEC holds,  $dx^n/dK > 0$ . By making trials more costly, this makes the threat of court greater, inducing increased safety effort so as to reduce the likelihood of entering that subgame.

Note that the fact that  $\delta^{\max}$ , the cap on a damages award, has FMC partials with the same sign as those with respect to  $K$ , makes an important point about the impact of applying caps: since  $FMC_{x\delta}^{f, \max} < 0$ , a reduction in  $\delta^{\max}$  (which would help the defendant, but hurt the plaintiff; see the Appendix) may result in lower safety effort, since it is loosening the cap which, under ISEC, results in  $dx^n/d\delta^{\max} > 0$ . In other words, under ISEC, if a cap is binding in the sense that  $\delta^{\max} < \delta$  for some types  $\delta$ , then loosening it may increase the equilibrium safety effort, while tightening it may reduce the equilibrium safety effort.

Finally, consider the effect of a reduction in the evidentiary standard (i.e., an increase in  $\sigma$ ). Proposition 5, part (ai), indicates that  $FMC_{x\sigma} < 0$  if and only if  $\hat{\theta}_x ETC_\sigma + \hat{\theta} ETC_{x\sigma} < 0$ . As shown in the Appendix,  $ETC_\sigma > 0$  and  $ETC_{x\sigma} > 0$ . Since  $\hat{\theta}_x < 0$  (by FOSD of F), then  $\hat{\theta}_x ETC_\sigma + \hat{\theta} ETC_{x\sigma} < 0$  if and only if  $-\hat{\theta}_x/\hat{\theta} > ETC_{x\sigma}/ETC_\sigma$ . Multiplying both sides of this last inequality by  $x$  yields a condition involving elasticities:  $-x\hat{\theta}_x/\hat{\theta} > xETC_{x\sigma}/ETC_\sigma$ . The expression  $x\hat{\theta}_x/\hat{\theta}$  is the elasticity of  $\hat{\theta}$ ; it measures the percentage reduction in the expected likelihood of an accident occurring due to a percentage increase in safety effort. On the right of the inequality is the elasticity of the marginal expected trial cost (marginal with respect to  $\sigma$ ).

Thus, a requirement for  $FMC_{x\sigma} < 0$  is that  $\hat{\theta}$  be sufficiently responsive to changes in  $x$ . The Ford Motor Company's design of the Pinto comes to mind. Viscusi (1991) discusses the design flaw in the Pinto, wherein the design engineers placed the gas tank only six inches in front of the rear bumper (that is, unusually close to the rear bumper); a modification that would have prevented 180 burn deaths per year would have cost \$11 per car (Viscusi, 1991, p. 111). This suggests that, in the case of the Pinto, the elasticity of  $\hat{\theta}$  with respect to safety effort is probably large, and thus that we might find in such a case that  $FMC_{x\sigma} < 0$ ; under ISEC this would then imply that reducing evidentiary standards would lead to increased safety effort.

To a significant degree, the results in the three-party case parallel the two-party results. In particular, with respect to  $K$  and  $\delta^{\max}$ , the same effects on  $FMC^f$  are found. In the case of  $\sigma$ , the analysis is more complicated, but we find that if  $FMC_{x\sigma} < 0$ , then  $FMC_{x\sigma}^f < 0$ ; in other words, if  $\hat{\theta}$  is sufficiently responsive to changes in  $x$ , then increasing  $\sigma$  induces more safety effort (under ISEC).

Thus, the issue now becomes: when is increasing safety effort welfare-enhancing? Let  $W(Q,X)$  be the planner's objective function:

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

To address the question of whether increases in a b-parameter are welfare-enhancing, we evaluate this function at the non-cooperative equilibrium, parametrized by b:  $W(q^n(x^n(b); b), x^n(b); b)$ , where  $b = K, \delta^{\max}$  or  $\sigma$ . Note that:

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

For  $t = 0$ ,  $x^n = \bar{x}^f$ , which in turn implies that  $FMC_x^f(x^n) = 0$  and  $FMC_x^S(x^n) < 0$  (assuming  $\phi > 0$ ). Then:

$$dW/db = Nn[-FMC_x^S(x^n)q^n(x^n)(dx^n/db) + (\beta + (n-1)\gamma)(Q^n(x^n) - q^n(x^n))(\partial q^n/\partial b) - FMC_b^S(x^n)q^n(x^n)].$$

Note that if  $\phi = 0$ , then the first term in the brackets above is zero, while the third term is negative. Since  $\partial q^n/\partial b = -FMC_b^f(x^n)/(2\beta + (n-1)\gamma) < 0$  for  $b = K, \delta^{\max}$  or  $\sigma$ , the second term is also negative, as  $Q^n(x^n) > q^n(x^n)$ . Hence, if  $\phi = 0$ ,  $dW/db < 0$  for  $b = K, \delta^{\max}$  or  $\sigma$ . In other words, in the absence of third-party harms, parameter changes that increase expected trial costs are welfare-reducing.

However, in the three-party case, sufficient conditions for  $dW/db$  to be positive are that:

i)  $Q^n(x^n) - q^n(x^n) < 0$ ; and ii)  $-FMC_x^S(x^n)(dx^n/db) - FMC_b^S(x^n) > 0$ . Condition (i) holds if  $\beta q^n(\bar{x}^f) < \phi \tilde{u}(\bar{x}^f)$ , which (as in Proposition 4) holds for sufficiently large values of  $n$ , or for  $\tilde{u}$  large enough. Condition (ii) requires that  $dx^n/db > FMC_b^S(\bar{x}^f)/[-FMC_x^S(\bar{x}^f)]$ , that is, if ISEC holds and  $dx^n/db$  is sufficiently large in magnitude.

Therefore, in the three-party case, increases in  $K, \delta^{\max}$  or  $\sigma$  (all of which increase expected trial costs) that induce increases in the equilibrium safety level are welfare-enhancing if the induced change in safety effort is sufficiently great, and if the third-party spillovers are sufficiently important. Note that, because of the technical complexity of the analysis, we performed the welfare computations assuming that  $t = 0$ . By continuity, there is also likely to be a portion of the parameter space such that increases in  $K, \delta^{\max}$  or  $\sigma$  improve  $W$  when  $t > 0$ .

## 7. Summary and Implications of the Analysis

We posed and examined 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 to third parties), lawsuits, and compensation, either via settlement or trial. Firm-level costs reflect both R&D 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 compared the market equilibrium safety effort and output levels to what a planner would choose. We considered two planners, one of whom was able to set safety standards, but took the market equilibrium output as given, and one of whom could control both safety effort and output. We argued that the former type of planner (RSP) was the better representative of what the tort system might do if faced with deciding upon a safety effort standard. The analysis led to a number of implications, both for the operation of the markets for such products and for the legal system adjudicating the resulting torts. We consider these in turn.

### Implications for Product Markets

In general, incorporation of design activities that influence the safety of a product undermines the traditional results that assert independence between the firm's decisions about safety effort and those about output level. When  $t > 0$ , the profit-maximizing level of safety effort does not minimize the per-unit marginal costs of production and liability (i.e., FMC or FMC<sup>f</sup>). Moreover, whether we consider the restricted social planner or the unrestricted social planner, this is true for the socially optimal level of safety effort, too. However, this does not necessarily mean that the market produces an inefficiently low amount of safety. We show that when the degree of product substitution is low, the market provides too little safety (with respect to both RSP's and USP's preferred amounts), 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. In other words, a sufficiently competitive market (though one that need not be particularly close to perfectly competitive) provides a sufficiently high level of safety effort, a level that will be inefficiently high due to competitive forces.

When third-party harms were added to the analysis, this continued to hold as long as the degree of spillover was sufficiently small (due either to small  $\phi$  or small  $\tilde{u}$ ), but equilibrium safety effort was always inefficiently low for products with large spillovers. This difference was due to the fact that while a consumer's willingness to pay was influenced by the firm's safety effort, non-consumers did not enter the market, so their losses were not directly accounted for by the firm.

We also showed that even if safety effort costs were not significant (i.e., if  $t = 0$ ), the presence of possible third-party harms meant that the market equilibrium safety effort level would be inefficient (in this case, inefficiently low). This reflected the other main difference between our model and the traditional analysis: we incorporated liability-related losses due to the presence of private information in settlement bargaining and court costs.

We further examined how firms would respond to increases in parameters (such as  $\phi$ ,  $K$ ,  $\delta^{\max}$  and  $\sigma$ ) that drive up FMC. If the cross-partial of FMC between such a cost-driver and safety effort was positive ( $FMC_{xb} > 0$ ), then the response of the firm was to cut both safety effort and output level; in this sense it was withdrawing from the market. On the other hand, if increases in safety effort ameliorated the cost-driver ( $FMC_{xb} < 0$ ), then we generally expected a mixed response from the firm:

increased safety and (likely) decreased output.

Finally, we found that changes in the cost-drivers listed above that reflect tort reform (i.e.,  $K$ ,  $\delta^{\max}$  and  $\sigma$ ) may have counter-intuitive effects on welfare. In the two-party case, anything that increases the expected costs of trial reduces welfare. However, in the three-party case, we showed that increases in court costs (increases in  $K$ ), loosening of caps on compensation (increases in  $\delta^{\max}$ ) and relaxation of evidentiary standards (increases in  $\sigma$ ) may not only cause firms to increase safety effort, but may also result in increases in welfare (if the increase in safety effort is large enough). Thus, it is important to understand both the technology of safety generation, as well as the composition of the victim population before the adoption of tort reforms that promise to tighten caps or raise evidentiary standards.

#### Implications for the Tort System

We employed strict liability throughout our analysis: if a firm's product is the source of harm, it must pay damages, independent of whether it took the socially optimal level of care (i.e., invested in the socially optimal level of safety effort). However, the restricted planner's solution has much to say about liability regimes such as negligence, wherein a firm would avoid liability by taking sufficient care. It should be clear from the analysis (whether  $t > 0$  or  $t = 0$ ) that this question (did the firm invest in sufficient safety effort?) will be close to impossible for a court to resolve. This is because, unlike the traditional analysis, decisions about safety effort and output level are intertwined. Essentially, a court could not determine the correct standard unless it performed a full analysis of the product market (the number of firms, the nature of the oligopolistic interaction, the degree of product substitutability, etc.) along with an analysis of the costs of safety design and product manufacture.

This also raises a question about the employment of the Hand Rule (see Posner, 1998) in tort

cases. The Hand Rule, proposed by Judge Learned Hand in a classic tort case,<sup>22</sup> argues that an injurer is at fault if the incremental benefit of an increase in care exceeds the incremental cost of providing it. These computations would, under the usual construction, be searching for the minimum of FMC (or FMC<sup>S</sup>) in our analyses. But, as we have seen (when  $t > 0$ ), in the two-party analysis, that level of care ( $\bar{x}$ ) is too high, while in the three-party setting (wherein the reference point would be  $\bar{x}^S$ ) it would either be too low or too high. The correct comparison point is  $X^{nq}$ , with all the attendant computational difficulties discussed above.

Thus, the foregoing discussion suggests yet one more reason why strict liability is likely to be preferred to negligence. Under strict liability, at least in the two-party case, market incentives due to competition may help with achieving (at least) socially optimal levels of safety effort. In fact, if the market is sufficiently competitive, firms will over-provide safety. Again, this is not because they are over-deterred by the liability system (since over-provision can arise even in the no-liability case), but because safety is a competitive attribute. Moreover, this suggests the policy response to handling cases with third-party harms: competition can be harnessed to provide incentives for firms to invest in sufficient safety effort if  $\tilde{u}$  can be reduced by shifting portions of it to  $\tilde{v}$ . In a loose sense, the greater the shift from  $\tilde{u}$  to  $\tilde{v}$ , the closer the firm's equilibrium safety effort level is likely to be to the socially optimal level (i.e.,  $x^n$  will be closer to  $X^{nq}$ ). The drawback to such shifting is that it will raise expected trial costs, as there will be fewer settlements.

Finally, the foregoing analysis assumed a "unilateral precaution" model; that is, only the firm's decisions about safety could influence the likelihood of harm or the level of damages, should harm occur. As the traditional analysis makes clear (see Shavell, 1987), strict liability does not provide the right incentives for care when both parties can influence the likelihood of harm. Thus,



an important extension of the foregoing analysis (but well beyond the current paper) would be to re-examine bilateral precaution in the extended model incorporating safety design costs and liability-related losses. The degree to which the market will still over-produce safety in such a setting is likely to depend upon the relative elasticities of  $\hat{\theta}$  and  $\hat{\delta}$  with respect to the firm's choice of safety effort when compared to the consumer's (or non-consumer's) choice of precaution. Cases wherein the firm's elasticities are high and the consumer's are low are still likely to exhibit graphs similar to Figure 2, while (as with the third-party analysis in Section 5) situations wherein the consumer's elasticities are greater than the firm's are likely to lead to universal under-supply of safety by firms (relative to the social optimum).

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## 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.

### Proofs of Assertions Made in the Text

#### Consumer-Victims

Equation (5), the first-order condition for firm  $i$ 's choice of safety, can be written as:

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

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

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

**Claim 1.** The firms' safety effort levels are strategic substitutes.

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

**Claim 2.** At the symmetric equilibrium safety effort level  $x^n$ , which is defined implicitly by  $H(x^n; a^n) = -(\alpha - \text{FMC}(x^n))\text{FMC}_x(x^n) - a^n = 0$ ,  $H_x(x^n; a^n) = -(\alpha - \text{FMC}(x^n))\text{FMC}_{xx}(x^n) + \{\text{FMC}_x(x^n)\}^2 < 0$ .

**Proof:** Substituting  $q^n = (\alpha - \text{FMC}(x^n)) / [2\beta + (n-1)\gamma]$  into (A.2) and evaluating at the symmetric equilibrium safety level  $x^n$  implies that:

$$-(\alpha - \text{FMC}(x^n))\text{FMC}_{xx}(x^n) + \{\text{FMC}_x(x^n)\}^2 \{ [2\beta + (n-2)\gamma]/(2\beta - \gamma) \} < 0. \quad (\text{A.3})$$

Notice that  $\{ [2\beta + (n-2)\gamma]/(2\beta - \gamma) \} \geq 1$ ; thus inequality (A.3) implies that  $H_x(x^n; a^n) = -(\alpha - \text{FMC}(x^n))\text{FMC}_{xx}(x^n) + \{\text{FMC}_x(x^n)\}^2 < 0$ . QED.

**Claim 3.** Strict concavity of the firm's profit function in own-safety implies  $H_x(x; a) < 0$  for all  $x$ .

**Proof:** Since we assume firm  $i$ 's reduced-form profit function is strictly concave in  $x_i$ , (A.2) holds for all  $x$  (not just for  $x^n$ ). Moreover, substituting  $q^n(x) = (\alpha - \text{FMC}(x)) / [2\beta + (n-1)\gamma]$  into (A.2) implies that (A.3) holds for all  $x$  (not just for  $x^n$ ). Finally, since  $\{ [2\beta + (n-2)\gamma]/(2\beta - \gamma) \} \geq 1$ , (A.3) implies that  $H_x(x; a) = -(\alpha - \text{FMC}(x))\text{FMC}_{xx}(x) + \{\text{FMC}_x(x)\}^2 < 0$  for all  $x$ . QED.

#### Consumer and Third-Party Victims

Notice that the equilibrium safety effort level when there are both consumer and third-party

victims is defined implicitly by the equation  $H^f(x^n; a^n) = -(\alpha - FMC^f(x^n))FMC_x^f(x^n) - a^n = 0$ . Upon noting the similarity of this equation to the consumer-victim case, it is apparent that Claims 1-3 are readily extended to the case of consumer and third-party victims by substituting  $FMC^f$  for  $FMC$ .

### Comparative Statics with respect to a Parameter b Affecting FMC

#### Consumer Victims

We have been able to summarize conveniently the effect of several parameters on  $x^n$  ( $X^{nq}$  and  $X^n$ , respectively) through the use of a function  $H(x; a)$  and a parameter  $a^n$  ( $A^{nq}$  and  $A^n$ , respectively) for which  $H(x^n; a^n) = 0$ . However, other parameters, which come from the litigation subgame, enter the problem through the function  $FMC(x) = m(x) + u(x) + v(x) = m(x) + \hat{\theta}(x)[\hat{\delta}(x) + ETC(x)]$ . One such example is the combined cost of trial (denoted  $K$ ), which affects expected trial costs. Since we will consider several such parameters in the remainder of the paper, we introduce the following more general analysis.

Let  $b \geq 0$  be a parameter that increases the full marginal cost per unit of output produced. If we denote this dependence by  $FMC(x; b)$ , then  $FMC_b(x; b) > 0$ . 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:  $dx^*/db = -H_b/H_x$ , where both numerator and denominator are evaluated at  $x^*$ . Since  $H_x < 0$ , the sign of  $dx^*/db$  is the same as the sign of  $H_b = FMC_x FMC_b - (\alpha - FMC)FMC_{xb}$ , and  $H_b > 0$  if and only if  $FMC_x/(\alpha - FMC) > FMC_{xb}/FMC_b$ . Moreover, we can determine the effect of an increase in  $b$  on the associated output level, denoted  $q^*$ , as follows:  $sgn\{dq^*/db\} = sgn\{-FMC_b - FMC_x(dx^*/db)\}$ . This is negative if and only if  $FMC_{xb}/FMC_b > FMC_{xx}/FMC_x$ , where again all expressions are evaluated at  $x^*$ . This leads to the following results.

**Result 1:** If  $FMC_{xb}(x; b) > 0$ , then  $dx^*/db < 0$ .

**Result 2:** If  $FMC_{xb}(x; b) < 0$ ,  $dx^*/db > 0$  if and only if  $FMC_x/(\alpha - FMC) > FMC_{xb}/FMC_b$ . We refer to this condition in the text as the "increasing safety effort condition" (ISEC).

**Result 3:**  $dx^*/db < 0$  implies  $dq^*/db < 0$ ;  $dx^*/db > 0$  implies [ $dq^*/db < 0$  if and only if  $FMC_{xb}/FMC_b > FMC_{xx}/FMC_x$ ].

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

Although there are two possible signs for  $dx^*/db$ , we will focus on  $dx^*/db > 0$  as being the most plausible outcome. This is because  $dx^*/db > 0$  for sufficiently small  $t$  or for sufficiently large  $N$  and/or  $\alpha$ . To see that this is true for sufficiently small  $t$  or sufficiently large  $N$ , recall that  $x^*$  is defined implicitly by  $-(\alpha - FMC(x; b))FMC_x(x; b) - a = 0$ , where  $a$  is proportional to  $t/N$ . Thus, as  $t/N \rightarrow 0$  (which occurs as  $t$  becomes vanishingly small or as  $N$  becomes arbitrarily large), it follows

that  $x^* \rightarrow \bar{x}$ . The ISEC condition holds at  $x = \bar{x}$ . By continuity, it also holds for  $x^* < \bar{x}$ , but sufficiently close to  $\bar{x}$ ; that is, ISEC holds for some non-zero  $t$  and finite  $N$ .

A similar argument can be made to show that ISEC holds for sufficiently large  $\alpha$ , since  $x^* \rightarrow \bar{x}$  as  $\alpha \rightarrow \infty$ . However, to see that  $\alpha$  need not be particularly large, note that for ISEC to hold requires  $\alpha > FMC + FMC_x[FMC_b/FMC_{xb}]$  at  $x^*$ . Since we know that  $x^* \in [0, \bar{x}]$ , a sufficient condition for ISEC to hold is that  $\alpha > \max\{FMC + FMC_x[FMC_b/FMC_{xb}] \mid x^* \in [0, \bar{x}]\}$ , which is a finite number since all the elements on the right-hand-side are bounded on  $[0, \bar{x}]$ . Finally, the inequality in Result 3,  $FMC_{xb}/FMC_b > FMC_{xx}/FMC_x$ , which ensures that  $dq^*/db < 0$ , holds when  $t$  is sufficiently small or when  $N$  and/or  $\alpha$  are sufficiently large; the proofs parallel those for ISEC.

### 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  $H^f(x^n; a^n, b) = -(\alpha - FMC^f(x^n; b))FMC_x^f(x^n; b) - a^n = 0$ . Upon noting the similarity of this equation to the consumer-victim case, it is apparent that Results 1-3 are readily extended to the case of consumer and third-party victims by substituting  $FMC^f$  for  $FMC$ .

### **Social Optimality with Third Parties and $t > 0$**

#### The Restricted Planner

Once again, we consider the choice of safety effort investment that a planner would make, first 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. The restricted planner's problem is:

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

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.

$$Q^{nq} = (\alpha - FMC^f(X^{nq})) / (2\beta + (n-1)\gamma), \quad (A.4)$$

and

$$\begin{aligned} & -(\alpha - FMC^f(X^{nq}))FMC_x^f(X^{nq}) - (t/N)[(2\beta + (n-1)\gamma)^2 / (3\beta + (n-1)\gamma)] \\ & + \phi [(2\beta + (n-1)\gamma) / (3\beta + (n-1)\gamma)] [\tilde{u}(X^{nq})FMC_x^f(X^{nq}) - \tilde{u}_x(X^{nq})(\alpha - FMC^f(X^{nq}))] = 0. \end{aligned} \quad (A.5)$$

What happens now to the relationship between  $x^n$  and  $X^{nq}$ ? If (counter-factually)  $\tilde{u}(\bullet) = \tilde{u}_x(\bullet) = 0$ , then (19) and (A.5) have the same solution for  $\gamma = \Gamma^{nq}(\beta, n)$ .<sup>23</sup> Since  $\tilde{u}(\bullet) > 0$  and  $\tilde{u}_x(\bullet) < 0$ , the last term in (A.5) matters; in what follows, assume that the last square-bracketed term in the second line of equation (A.5) is positive:  $[\tilde{u}(X^{nq})FMC_x^f(X^{nq}) - \tilde{u}_x(X^{nq})(\alpha - FMC^f(X^{nq}))] > 0$ . Then at  $\gamma = \Gamma^{nq}(\beta, n)$ , the solution to (19) is now less than the solution to (A.5); that is, at this value of  $\gamma$ ,  $x^n < X^{nq}$ , so the equilibrium safety effort is now less than the (restricted) socially optimal level. Note that, in general,  $\tilde{u}_x(x)/\tilde{u}(x)$  is independent of  $\phi$  and  $FMC_x^f(x)/(\alpha - FMC^f(x))$  is decreasing in  $\phi$ , so it would not be particularly surprising that  $\tilde{u}_x(x)/\tilde{u}(x) > FMC_x^f(x)/(\alpha - FMC^f(x))$  for some values of  $x$ ,

especially if  $\phi$  were large.

Alternatively, if  $[\tilde{u}(X^{nq})FMC_x^f(X^{nq}) - \tilde{u}_x(X^{nq})(\alpha - FMC^f(X^{nq}))] < 0$ , 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:

$$\begin{aligned} & [\tilde{u}(X^{nq})FMC_x^f(X^{nq}) - \tilde{u}_x(X^{nq})(\alpha - FMC^f(X^{nq}))] > 0 \text{ if and only if} \\ & FMC_x^f(X^{nq})/(\alpha - FMC^f(X^{nq})) > \tilde{u}_x(X^{nq})/\tilde{u}(X^{nq}). \end{aligned}$$

Thus, if  $\tilde{u}$  is fairly unresponsive to  $x$  (i.e., if  $\tilde{u}(x)$  is sufficiently inelastic), so that  $\tilde{u}_x(X^{nq})/\tilde{u}(X^{nq}) > FMC_x^f(X^{nq})/(\alpha - FMC^f(X^{nq}))$ , then starting at  $\gamma = \Gamma^{nq}(\beta, n)$ , RSP would choose a smaller safety effort level than the market (with third-party victims present) chooses in equilibrium. This is because by reducing  $X^{nq}$ , the planner can reduce  $N\phi Q^{nq}\tilde{u}(X^{nq})$ , the total expected third-party loss, via the effect of  $X^{nq}$  on  $Q^{nq}$  (which, since  $\tilde{u}$  is unresponsive to  $x$ , is the only effective way to reduce spillovers).

#### The Unrestricted Planner

Next we consider the unrestricted planner's choice of safety effort and output, now in the presence of third parties:

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

Let  $(X^n, Q^n)$  solve USP's problem; then they satisfy the following conditions:

$$Q^n = (\alpha - FMC^S(X^n))/(\beta + (n-1)\gamma), \quad (\text{A.6})$$

and

$$-(\alpha - FMC^S(X^n))FMC_x^S(X^n) - (t/N)(\beta + (n-1)\gamma) = 0. \quad (\text{A.7})$$

Since  $t > 0$ ,  $X^n < \bar{x}^S$ . To understand the relationship between  $x^n$  and  $X^n$ , we re-write (A.7) as:

$$\begin{aligned} & -(\alpha - FMC^f(X^n))FMC_x^f(X^n) - (t/N)(\beta + (n-1)\gamma) \\ & + \phi[\tilde{u}(X^n)FMC_x^S(X^n) - \tilde{u}_x(X^n)(\alpha - FMC^S(X^n)) - \phi\tilde{u}(X^n)\tilde{u}_x(X^n)] = 0. \end{aligned} \quad (\text{A.8})$$

Now recall (19), the firm's first-order-condition for the choice of safety effort, which can be re-expressed as:

$$\begin{aligned} & -(\alpha - FMC^f(x^n))FMC_x^f(x^n) \\ & - (t/N)[(2\beta - \gamma)(2\beta + (n-1)\gamma)^2]/[(2\beta - \gamma)(2\beta + (n-1)\gamma) + \gamma^2(n-1)] = 0. \end{aligned} \quad (\text{A.9})$$

From its definition in Section 4, at  $\gamma = \Gamma^n(\beta, n)$ , the terms multiplying  $(t/N)$  in (A.8) and (A.9) are equal, so that at  $\gamma = \Gamma^n(\beta, n)$ ,  $x^n = X^n$  if  $\tilde{u}(\bullet) = \tilde{u}_x(\bullet) = 0$ . However, since  $\tilde{u}(\bullet) > 0$  and  $\tilde{u}_x(\bullet) < 0$ , when  $\phi > 0$  and the term in square brackets in (A.8) is positive, then  $x^n < X^n$  at  $\gamma = \Gamma^n(\beta, n)$ . This last result holds because the sign of the left-hand-side of (A.8) at  $x^n$  is positive; hence,  $X$  needs to be increased to achieve optimality for USP. Thus, at  $\gamma = \Gamma^n(\beta, n)$ ,  $x^n > X^n$  if and only if  $[\tilde{u}(X^n)FMC_x^S(X^n) - \tilde{u}_x(X^n)(\alpha - FMC^S(X^n)) - \phi\tilde{u}(X^n)\tilde{u}_x(X^n)] > 0$ .

### Summary of the Settlement Subgame and How its Parameters Affect Full Marginal Cost Consumer Victims

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  $(x^n, q^n)$ ,  $(X^{nq}, Q^{nq})$ , and  $(X^n, Q^n)$ .

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  $\theta$  and  $\delta$ , 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  $\sigma$  which represents, for example, the ease of demonstrating causality, and a parameter  $\delta^{\max}$ , 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  $\delta$  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:

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

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

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  $\delta^{\max}$  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 partially borne by each party). Finally,



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

Under our maintained assumptions that  $\delta^{\max} > \hat{\delta}(x) = \hat{\delta} + 1/\mu(x)$  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  $ETC_{x\delta^{\max}} < 0$ .

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, (4)  $FMC_K > 0$  and  $FMC_{xK} < 0$ ; (5)  $FMC_\sigma > 0$  and  $FMC_{x\sigma} < 0$  ( $> 0$ ) as  $\hat{\theta}_x ETC_\sigma + \hat{\theta}(x) ETC_{x\sigma} < 0$  ( $> 0$ ); and (6)  $FMC_{\delta^{\max}} > 0$  and  $FMC_{x\delta^{\max}} < 0$ .

Assuming that ISEC holds, these signs imply that  $dx^n/db > 0$ ,  $dX^{nq}/db > 0$ , and  $dX^n/db > 0$ , for  $b = K, \delta^{\max}$  and  $\sigma$  (if  $FMC_{x\sigma} < 0$ ; if  $FMC_{x\sigma} > 0$ , then  $dx^n/d\sigma < 0$ ,  $dX^{nq}/d\sigma < 0$  and  $dX^n/d\sigma < 0$ ). Thus, an increase in trial costs or the damage award cap will result in increased safety and decreased output. The same response pattern holds for an increase in  $\sigma$  if  $FMC_{x\sigma} < 0$  (which is true if the risk of accident is relatively responsive to  $x$ ), while if  $FMC_{x\sigma} > 0$  (which is true if the risk of accident is relatively unresponsive to  $x$ ) then both safety and output decrease when  $\sigma$  increases.

Finally, 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:

- (7)  $EL_{DK} > 0$  and  $EL_{DxK} = 0$ ; (8)  $EL_{D\sigma} > 0$  and  $EL_{Dx\sigma} < 0$ ; (9)  $EL_{D\delta^{\max}} > 0$  and  $EL_{Dx\delta^{\max}} < 0$ ;  
 (10)  $EL_{PK} > 0$  (assuming  $\sigma/\mu(x) > K/(2^{1/2} - 1)$  and the cap  $\delta^{\max}$  is sufficiently large) and  $EL_{PxK} < 0$ ;  
 (11)  $EL_{P\sigma} < 0$  and  $EL_{Px\sigma} > 0$ ; and (12)  $EL_{P\delta^{\max}} < 0$  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  $\sigma$  or  $\delta^{\max}$ , 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.

### Consumer and Third-Party Victims

Recall that  $FMC^f(x)$  can be written as:  $FMC^f(x; \phi) = FMC(x) + \phi \tilde{v}(x_i)$ , where  $\tilde{v}(x_i) = \hat{\theta}(x)EL_D(x)$ . Therefore, it follows that  $FMC_\phi^f > 0$  and  $FMC_{\phi x}^f < 0$ . Moreover, the properties of  $FMC^f$  with respect to the parameters  $K, \sigma$  and  $\delta^{\max}$  are the same as those of  $FMC$  (as given in (4)-(6) above) with the possible exception of  $FMC_{\phi \sigma}^f = FMC_{\phi \sigma} + \phi \hat{\theta}(x)EL_{D\sigma} + \phi \hat{\theta}(x)EL_{Dx\sigma}$ . Since the second two terms are negative,  $FMC_{\phi \sigma}^f < 0$  if  $FMC_{\phi \sigma} < 0$ ; otherwise, the sign of  $FMC_{\phi \sigma}^f$  may be positive. Under ISEC, this implies that  $dx^n/db > 0$ , for  $b = \phi, K, \delta^{\max}$  (and  $\sigma$ , if  $FMC_{\phi \sigma}^f < 0$ ).

Similarly,  $FMC^s(x_i) = FMC(x_i) + \phi(\tilde{u}(x_i) + \tilde{v}(x_i)) = FMC(x) + \hat{\theta}(x)[\hat{\delta}(x) + ETC(x; K, \sigma, \delta^{\max})]$ . Therefore, it follows that  $FMC_\phi^s > 0$  and  $FMC_{\phi x}^s < 0$ . Moreover, the properties of  $FMC^s$  with respect to the parameters  $K, \sigma$  and  $\delta^{\max}$  are exactly the same as those of  $FMC$  (as given in (4)-(6) above). Under ISEC, this implies that  $dx^n/db > 0$ , for  $b = \phi, K, \delta^{\max}$  (and  $\sigma$ , if  $FMC_{\phi \sigma}^s < 0$ ).

## Endnotes

1. In our model, consumers are not fully-insured by strict liability since they bear residual harm and litigation costs, but well-informed consumers subtract any residual expected losses from their willingness to pay for the product. Thus, the slope of the demand curve is unaffected by safety in our model. Moreover, combined marginal production and liability costs are decreasing in safety at the firm's optimum, so a monopolist always under-provides safety relative to the level that would be chosen by a social planner. However, as we will see, this need not be true for an oligopoly.
2. Other papers that assume safety effort involves a constant expenditure per unit of output, and which obtain the same results under strict liability, include Hamada (1976) and Epple and Raviv (1978). Shavell (1980) examines a variety of liability rules and considers cases of bilateral safety effort as well. Polinsky (1980) further shows that under strict liability (assuming that litigation is not costly) the equilibrium number of firms will be socially optimal.
3. Tort reform has been an on-going policy question of importance which, as of this writing, is heating up again. See, for example, VandeHei (2002), Ballard (2003), and Caher (2003).
4. The use of  $x$ , or a parameter, as a subscript on a function indicates differentiation.
5. 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.
6. 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.
7. See Spence (1977), Shavell (1980, 1987 and forthcoming) and Polinsky and Rogerson (1983) for analyses of liability when consumers may mis-perceive the level of safety. 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 consumers can infer the level of safety from the price charged by the firm.
8. Note, we do not consider the case of a social planner who can also manipulate the number of firms. A detailed analysis is beyond the scope of this paper, but allowing products which are imperfect substitutes suggests that social optimality may involve  $n > 1$ .
9. 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.
10. 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).

11. This profit function is similar to that in the cost-reducing R&D literature (see, especially, Kamien, Muller and Zang, 1992). In that literature  $x$  is investment in R&D to reduce marginal production costs. In our model, marginal production costs are increasing in  $x$ , but since marginal liability costs decrease in  $x$ , FMC is U-shaped in  $x$ . We will indicate below some results that are common to the two literatures.

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

13. Moreover, safety effort levels are strategic substitutes, that is, using (5) above 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.

14. To make use of the results for  $H$  from Section 2, we need to guarantee that the second-order condition for firm  $i$ 's profit-maximization problem (found before applying symmetry) produces the correct property for  $H_x$  when symmetry is applied. It does; see the Appendix for details.

15. Our equation (7) is similar to equation (9) in Kamien, Muller and Zang (1992, p. 1299). However, their analysis focuses on a "knowledge-spillover" parameter (absent here) and does not examine comparative statics with respect to other parameters which are of interest here, such as  $n$  and  $\gamma$ , as well as those which affect FMC (see below). Moreover, they do not compare equilibrium R&D with a social planner's choice, but rather with that of a research joint venture.

16. We extend our discussion in Section 2 to a similar set of conditions on  $H^f$  as used there for  $H$ .

17. Of course, if  $\phi = 0$ , or if  $\tilde{u}(\bullet) = \tilde{u}_x(\bullet) = 0$ , then  $t = 0$  implies that  $X^{nq} = \bar{x}^f$ , and then the market and the planner agree. This is (essentially) the traditional model.

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

19. 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 reject, both parties go to trial where a court correctly determines the relevant private information and makes the appropriate transfer.

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

21. For convenience, we assume that  $\tilde{G} = G$ . Note also that, for this distribution, both the screening and signaling games have the same expected trial costs  $ETC(x)$  when  $\delta^{\max} \rightarrow \infty$ .

22. *United States v. Carroll Towing Co.*, 159 F.2d 169 (2d Cir. 1947). The Restatement (3<sup>rd</sup>) of Torts emphasizes an increased use of the Hand Rule in negligence cases.

23. 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.