Economics Bulletin

Volume 43, Issue 4

Tort reform and contingent incomplete liability

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Abstract

A surprising array of US manufacturers enjoy broad immunity from tort liability for public harm. We present a positive analysis of the consequences of such immunity with a model of buyer and manufacturer care-taking in a market relationship that features incomplete liability assignment and a probability that the representative manufacturer could lose its immunity as the public grows frustrated with increasing public harm. We refer to this combination of features as 'contingent incomplete liability'. We find that reduced manufacturer liability vis-a-vis tort reform can lead to less harmful products. However, for this to obtain, liability must be contingent and the probability all liability shifts to the manufacturer must be a function of its care choice. If liability is not contingent, and under a broad range of conditions when it is contingent, reducing manufacturer liability for public harm leads to less safe products. Regardless of whether tort reform leads to safer or less safe products, expected social welfare is lower in competitive markets.

We appreciate helpful comments and suggestions from an anonymous reviewer; from Nathan Chan; and from seminar participants at the University of Massachusetts-Lowell, University of Massachusetts-Amherst, the University of Missouri-Columbia, the University of Illinois-Urbana, and session colleagues at the 2019 conferences of the New York State Economics Association and of the Southern Economics Association. An earlier version of this paper circulated with title "Tort Reform, Public Harm, and Welfare".

Citation: John Stranlund and Jeffrey Wagner, (2023) "Tort reform and contingent incomplete liability", *Economics Bulletin*, Volume 43, Issue 4, pages 1718-1729
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Submitted: July 12, 2023. **Published:** December 30, 2023.

1 Introduction

A surprisingly diverse array of US producers enjoy broad immunity from tort liability for public harm vis-à-vis versions of tort reform. For instance, the federal Protection of Lawful Commerce in Arms Act (PLCAA) of 2005 grants the firearms industry immunity from liability for crimes committed with its products. And the fast food and sugar-sweetened beverage industries are immunized from liability for private and public health damages by state-level tort reforms known as commonsense consumption acts (CCAs) in 26 US states (Carpenter and Tello-Trillo, 2015; Pomeranz et al., 2019; Allcott et al., 2019). Public harm in these contexts comprises private health care costs that are passed on to public insurance funds. Such immunity arose primarily on the perception that these manufacturers are not reasonably culpable for harm (and culpability is necessary though not sufficient for a finding of liability). Advocates for tort reform generally maintain that shifting culpability for harm from manufacturers to the buyers of their products, and relying on the fact that manufacturers and buyers are in a disciplining market relationship, can reduce risks and, by implication, raise social welfare.[1] We investigate these claims theoretically with a positive model of care taking to reduce expected public harm by both buyers and producers in a competitive market relationship. Hay and Spier (2005)—HS, henceforth—features several elements useful for analyzing relatively unexplored tensions in tort reform that run through the aforementioned industries: (1) bilateral care taken sequentially by a representative manufacturer and buyer in a market relationship; (2) public harm that is generated by the use of a product; and (3) a buyer who may not face all the liability for public harm. We extend the HS framework by incorporating the contribution in Daughety and Reinganum (2006) that liability shares may not be completely assigned and by adding two elements: a manufacturer granted immunity from liability may nevertheless face some probability that its immunity could be reversed, and this probability could be endogenous to the manufacturer's observable care. We refer to the combination of incomplete liability and a probability that all liability shifts to a manufacturer that may depend on its choice of care as 'contingent incomplete liability'.

The rationales for investigating theoretically how these two factors interact to affect care taking, public harm, and welfare are as follows. First, incomplete liability shares could result from shifting liability from manufacturers to buyers that are partially or completely judgment-proof, but could also result from other factors including legal errors (Boyer and Porrini, 2011), high litigation and settlement costs (Hylton, 1990), and imperfect information amongst the harmed public as to their rights to bring suit (Daughety and Reinganum, 2002). Second, a manufacturer could lose its immunity with positive probability as the public, through its legislatures/courts, grows frustrated with public harm. There is evidence that liability shares are indeed socially contingent and therefore subject to change—and sometimes abruptly. For example, Currie and MacLeod (2008, 801) describe how some state medical malpractice tort law reforms were repealed by legislatures or ruled unconstitutional by courts. Sonner (2013) and others suggest that federal laws that currently shield the firearms industry from liability for crimes committed with their products are not ironclad but rather socially contingent. And Choi (2019) argues that manufacturers in information-rich industries such as autonomous vehicle production are increasingly aware that their culpability for private and public harm from software failures is vulnerable to legislative and/or judicial revision. Third, in our model the probability that the manufacturer loses its immunity could be increasing in

[1] See, e.g.. Polinsky and Shavell (2009).

its observable care—if increasing care may be construed as an admission of culpability or a duty of care—or decreasing in its observable care, if society perceives that efforts to make products safer justify continued immunity. For instance, Wagner (1996) and Dana (2010) caution that a manufacturer's liability could increase if it undertakes product testing and discloses (that is, makes observable to potential plaintiffs and the courts) the care it has taken and the safety issues such testing revealed.

Our model shows how this real-world possibility of immunity reversal affects bi-lateral care taking, public harm and social welfare. As per a stated goal of tort reform, we find it is possible for product safety to improve as the manufacturer's share of liability for public harm falls. However, our take-home finding is that contingent liability is a necessary (though not sufficient) condition for this to occur. That is, there must be some probability that all liability shifts to the manufacturer, and this probability must be a function of its care choice. If liability is not contingent, and under a broad range of conditions when it is contingent, reducing manufacturer liability for public harm leads to less safe products. Regardless of whether reducing the manufacturer's liability share leads to more or less product safety, we demonstrate that even as market participants are better off with tort reform, expected harm borne by the public strictly increases and expected social welfare strictly declines with reduced manufacturer liability for public harm in competitive product markets.

2 Model fundamentals

As in HS (2005), we consider a representative manufacturer, m, and a representative buyer, b, in a market for a consumption good that can cause public harm for which the manufacturer or buyer or some combination could be found culpable and liable.[2] Both parties are risk-neutral. The marginal cost of producing and selling q units to the buyer is normalized to zero. The buyer has a quasi-linear utility function

$$U(q) = \int_0^q P(z)dz + y, \tag{1}$$

where $P(q)$ is the buyer's strictly declining marginal benefit for units of the good and y is a numeraire commodity with price equal to one. Both the manufacturer and the buyer take observable care, x^m and x^b, respectively, per unit of q to reduce expected harm, $H(x^m,x^b)$, per unit. The expected harm function is strictly convex. The sign of $\partial^2 H/\partial x^m \partial x^b$ depends upon whether manufacturer care and buyer care are substitutes, complements, or independent of each other in the reduction of expected harm. In particular, $\partial^2 H/\partial x^m \partial x^b$ is positive (negative) when care types are substitutes (complements), as the marginal harm avoided decreases (increases) as the other care type increases (Bartsch, 1997). Manufacturer and buyer care have independent effects on expected harm if $\partial^2 H/\partial x^m \partial x^b = 0$. The marginal cost of care taken by either party is one.

Under these conditions the social welfare function is

$$SW(q,x^m,x^b) = \int_0^q [P(z) - H(x^m,x^b) - x^m - x^b]dz. \tag{2}$$

The first-best levels of quantity, q^*, and care, x^{m*} and x^{b*}, maximize (2). The assumptions that $P(q)$ is strictly decreasing and $H(x^m,x^b)$ is strictly convex guarantee that these levels are unique.

[2] We (and HS) abstract from the possibility that consumption also causes private harm; we assume that the consumer's marginal benefit is net of expected private harm.

In addition, we assume strictly positive amounts of the choice variables throughout our work.

We characterize the equilibrium levels of manufacturer care, buyer care and output under strict liability rules that may not assign complete liability for public harm to the buyer, with some residual liability assigned to the manufacturer. Thus, assume a strict liability rule for which the buyer is liable for and has assets to pay a percentage $\delta^b \in [0,1]$ of harm and the manufacturer is liable for and has assets to pay the percentage of harm $\delta^m \in [0,1]$. We consider three real-world possibilities, and refer to their combination as contingent incomplete liability. First, liability may not be completely assigned, so we allow $\delta^m + \delta^b \leq 1$. Second, the manufacturer may have partial or complete immunity from liability, but that this immunity may be removed. Hence, suppose there is some probability that liability shifts entirely to the manufacturer (effectively, $\delta^b = 0$ and $\delta^m = 1$). Third, this probability may depend on the manufacturer's choice of care. In our analysis this probability is weakly positive but it is strictly less than one. Let $\rho(x^m) \in [0,1)$ denote the probability that all liability shifts to the manufacturer. We can envision $\rho(x^m)$ as the product of (1) the probability that a manufacturer's care will be so great as to trigger a finding of culpability or a duty of care and (2), conditional on (1), the probability that a manufacturer's care will be judged robust enough to warrant keeping its immunity from liability. Hence, $\rho'(x^m)$ can be positive if it is not clear that the manufacturer has a duty of care and negative when the manufacturer knows it has a duty of care, and therefore taking more care can reduce $\rho(x^m)$.

The timing in the model is as follows. The manufacturer moves first with its care choice. Then, the buyer observes the manufacturer's care choice and simultaneously chooses the number of units of the good to purchase and their own care. Liability is assigned in the final stage; either $\delta^m \geq 0$, $\delta^b > 0, \delta^m + \delta^b \leq 1$ with probability $1 - \rho(x^m)$, or $\delta^m = 1, \delta^b = 0$ with probability $\rho(x^m)$. We emphasize that ours is a positive model, so the liability shares and $\rho(x^m)$ are exogenous rather than endogenous policy choices.

Under the conditions of the model the manufacturer's expected profit is

$$B(q,x^m) = \Big[p - H(x^m,x^b)(\delta^m + (1-\delta^m)\rho(x^m)) - x^m\Big]\, q, \tag{3}$$

where p is the endogenous price of q. Assume that the representative manufacturer is perfectly competitive. (We have examined the consequences of imperfect product competition and the results are available upon request.) The buyer's budget constraint is

$$w = \Big[H(x^m,x^b)\delta^b(1-\rho(x^m)) + x^b + p\Big]\, q + y, \tag{4}$$

where w is the consumer's wealth. Since the buyer's care choice does not enter its utility function directly, its strategic response to the manufacturer's care minimizes their expected liability and cost of care per-unit of consumption, $H(x^m,x^b)\delta^b(1-\rho(x^m)) + x^b$. Denote the buyer's best response to the manufacturer's level of care, given their liability share, as

$$x^b = r^b(x^m, \delta^b). \tag{5}$$

Our first proposition, which is only slightly modified from HS, characterizes the competitive equilibrium levels of care and output. All proofs are in the appendix.

Proposition 1: Let the competitive equilibrium levels of care and output be $(\widehat{x}^m, \widehat{x}^b, \widehat{q})$. These values are characterized by the following equations:

$$\widehat{x}^m = argmin_{x^m} H(x^m, r(x^m, \delta^b)) \left(\delta^m + \delta^b + (1-\delta^m-\delta^b)\rho(x^m)\right) + x^m + r^b(x^m, \delta^b); \quad (6)$$

$$\widehat{x}^b = r^b(\widehat{x}^m, \delta^b) \quad (7)$$

$$P(\widehat{q}) = H(\widehat{x}^m, \widehat{x}^b) \left(\delta^m + \delta^b + (1-\delta^m-\delta^b)\rho(\widehat{x}^m)\right) + \widehat{x}^m + \widehat{x}^b. \quad (8)$$

We assume that the equilibrium choices of care and output, $(\widehat{x}^m, \widehat{x}^b, \widehat{q})$, are unique. Note that

$$H(x^m, x^b) \left(\delta^m + \delta^b + (1-\delta^m-\delta^b)\rho(x^m)\right) + x^m + x^b$$

is the manufacturer's and the buyer's combined expected liability and care costs per unit of output, which we will refer to as the *expected per-unit market cost* of the good. Thus, eq. (6) states that, given the buyer's strategic choice of care, the manufacturer's care choice minimizes the expected per-unit market costs of production and use of the product. Eq. (8) states that the equilibrium output equates the buyer's marginal benefit to the expected per-unit market cost of producing and using the product.

It is straightforward to show under perfect competition that the market achieves first-best levels of care and output if and only if the consumer bears all liability for public harm, the manufacturer is completely immune, and there is no chance that the manufacturer will lose its immunity. That is, $(\widehat{x}^m, \widehat{x}^b, \widehat{q}) = (x^{m*}, x^{b*}, q^*)$ if and only if $\delta^b = 1$, $\delta^m = 0$ and $\rho(x^m) = 0$.[3] This result is the same as in HS Proposition 1 except for the consideration of $\rho(x^m)$. In this context the manufacturer chooses to embed socially optimal care in its product, because the buyer is willing to pay for it to optimally manage their own liability for public harm. However, if liability is not completely assigned to the buyer, then Proposition 2 in HS states that the second-best strict liability rule pushes the residual liability to the manufacturer, thus maintaining $\delta^m + \delta^b = 1$. (We will confirm that this second-best result also holds in our framework at a later point in our analysis.) In contrast, in our work: (1) liability may be incompletely assigned–because of factors that may include judgment-proofness, court error, or asymmetric information–thus maintaining $\delta^m + \delta^b < 1$; (2) there may be some probability that all the liability will shift to the manufacturer so that $\rho(x^m) > 0$; and (3) the manufacturer's choice of care can change this probability.

3 Market and welfare effects of contingent incomplete liability and tort reform under perfect competition

In this section we present the main results of our analysis. We consider the effects of a common type of tort reform that reduces manufacturer liability while holding the buyer's liability fixed. We first determine the conditions under which this kind of tort reform can lead to a safer product. We find that reduced manufacturer liability can lead to a safer product, but only if liability is

[3] The "only if" part of this statement does not hold if x^m and x^b are perfect substitutes in reducing per-unit expected harm. In this case, it can be shown that the first-best outcome is achieved even though $\delta^b < 1$ and $\rho(x^m) \geq 0$ as long as all residual liability is assigned to the manufacturer.

contingent and the probability all liability shifts to the manufacturer is affected by its choice of care. We then consider the market and welfare effects of reducing manufacturer liability. We find that even if reduced manufacturer liability results in a safer product, expected social welfare is lower in competitive markets.

To determine whether tort reform results in a more or less harmful product we need to sign

$$\frac{\partial \widehat{H}}{\partial \delta^m} = \left(\frac{\partial H}{\partial x^m} + \frac{\partial H}{\partial x^b} \frac{\partial r^b}{\partial x^m} \right) \frac{\partial \widehat{x}^m}{\partial \delta^m}, \tag{9}$$

where, to conserve notation, we define $\widehat{H} = H(\widehat{x}^m, \widehat{x}^b)$. Below we will define $\widehat{\rho} = \rho(\widehat{x}^m)$. (We have dropped all the function arguments in (9), and will do so from now on except when it is useful to show these arguments.) The last term on the right side of (9) is the marginal effect of the manufacturer's liability share on its choice of care. The term in parentheses contains the direct effect of the manufacturer's choice of care on per-unit expected harm and the indirect effect of this choice on expected harm that works through the buyer's reaction to the manufacturer's choice of care. A reduction in the manufacturer's share of liability results in a safer product if (9) is strictly positive; the product is more harmful if (9) is negative. From here on let

$$\frac{\partial \widetilde{H}}{\partial x^m} = \frac{\partial H}{\partial x^m} + \frac{\partial H}{\partial x^b} \frac{\partial r^b}{\partial x^m}, \tag{10}$$

and in turn,

$$\frac{\partial \widehat{H}}{\partial \delta^m} = \frac{\partial \widetilde{H}}{\partial x^m} \frac{\partial \widehat{x}^m}{\partial \delta^m}. \tag{11}$$

Note that a change in manufacturer liability does not affect how harmful the product is if either $\partial \widehat{x}^m / \partial \delta^m = 0$ or $\partial \widetilde{H} / \partial x^m = 0$, but these are special cases that we can ignore for the purposes of our discussion.

The following proposition reveals necessary and sufficient conditions under which a reduction in the manufacturer's liability share leads to a safer product.

Proposition 2: Given $\partial \widehat{x}^m / \partial \delta^m \neq 0$ and $\partial \widetilde{H} / \partial x^m \neq 0$, a reduction in the manufacturer's share of liability results in strictly lower expected public harm per unit of output (i.e., a safer product) if and only if

$$-sgn\left(\frac{\partial r^b}{\partial x^m} + 1 + \widehat{H}(1 - \delta^m - \delta^b)\widehat{\rho}' \right) = sgn\left(\widehat{\rho}' - \frac{(1-\widehat{\rho})}{\widehat{H}} \frac{\partial \widetilde{H}}{\partial x^m} \right). \tag{12}$$

Proposition 2 suggests that reducing manufacturer liability has an ambiguous effect on per-unit expected public harm, so this issue is an empirical matter to be resolved case-by-case. We explore some of the necessary conditions under which reduced manufacturer liability leads to a safer or more harmful product with two corollaries that follow from Proposition 2.

Corollary 1: Given $\partial \widehat{x}^m / \partial \delta^m \neq 0$ and $\partial \widetilde{H} / \partial x^m \neq 0$, reducing the manufacturer's share of liability can result in strictly lower expected public harm per unit of output, but only if the probability that all liability will shift to the manufacturer is a function of the manufacturer's care.

Corollary 1 states that a necessary (though not sufficient) condition for reducing manufacturer liability to result in a safer product is that the manufacturer's immunity (perhaps partial immunity) from liability is contingent and that the probability all liability shifts to the manufacturer depends on its care choice. Our next corollary provides necessary conditions regarding that probability's dependence and the strategic interaction between the buyer and manufacturer for a reduction in the manufacturer's share of liability to yield a safer product.

Corollary 2: If reducing the manufacturer's share of liability results in lower expected public harm per unit of output, then it must be true that either: (1) $\widehat{\rho}' > 0$ and $\partial r^b/\partial x^m < -1$; or (2) $\widehat{\rho}' < 0$ and $\partial r^b/\partial x^m > -1$.

Consider case 1 in Corollary 2. In this case, tort reform produces a safer product because $\partial \widetilde{H}/\partial x^m > 0$ and $\partial \widehat{x}^m/\partial \delta^m > 0$, which requires $\partial r^b/\partial x^m < -1 - \widehat{H}(1-\delta^m-\delta^b)\widehat{\rho}'$, and that $\widehat{\rho}'$ is positive and large enough to offset $-((1-\widehat{\rho})/\widehat{H})(\partial \widetilde{H}/\partial x^m) < 0$ in (12). These imply that the buyer considers its care and the manufacturer's care to be strong strategic substitutes so that a dollar reduction in the manufacturer's care choice motivates the buyer to increase its care choice by more than a dollar. Thus, as the manufacturer's liability share is reduced, it reduces its level of care ($\partial \widehat{x}^m/\partial \delta^m > 0$), but the buyer more than makes up for it by significantly increasing their level of care, resulting in lower expected harm per unit ($\partial \widetilde{H}/\partial x^m > 0$). So that the manufacturer reduces its care as its liability is reduced ($\partial \widehat{x}^m/\partial \delta^m > 0$), the probability liability shifts to the manufacturer must be strictly increasing in its care choice ($\widehat{\rho}' > 0$) to a sufficient degree.

On the other hand, case 2 of Corollary 2 involves $\partial \widetilde{H}/\partial x^m < 0$ and $\partial \widehat{x}^m/\partial \delta^m < 0$, which requires $\partial r^b/\partial x^m > -1 - \widehat{H}(1-\delta^m-\delta^b)\widehat{\rho}'$, and that $\widehat{\rho}'$ is negative and small enough to offset $-((1-\widehat{\rho})/\widehat{H})(\partial \widetilde{H}/\partial x^m) > 0$ in (12). In this case, $\partial r^b/\partial x^m > -1$ so that the buyer considers its care choice to be a weak substitute, neutral, or a complement of the manufacturer's choice of care. This leads to an inverse relationship between the manufacturer's choice of care and expected harm per-unit of output ($\partial \widetilde{H}/\partial x^m < 0$). Moreover, to make sure that the manufacturer's choice of care rises with a reduction in its share of liability ($\partial \widehat{x}^m/\partial \delta^m < 0$), the probability liability shifts entirely to the manufacturer must be decreasing in the manufacturer's care choice ($\widehat{\rho}' < 0$) to a sufficient degree.

Corollaries 1 and 2 focus on only necessary conditions for tort reform to result in a safer product. In fact, there is a wide set of outcomes in which the conditions identified in the corollaries hold but tort reform produces a more harmful product. For one set of examples, our discussion of Corollary 2 reveals that the dependence of the probability that all liability shifts to the manufacturer on its care choice must be sufficiently large (in absolute value in case 2) for tort reform to result in a safer product. If this dependence is weaker, then reducing the manufacturer's liability share will lead to a less safe product. There is also a large set of outcomes that do not satisfy the conditions of the corollaries, resulting in a more harmful product. Of course, if liability is not contingent, or if it is contingent but the probability that all liability shifts to the manufacturer is not affected by its care choice, then the conditions of Corollary 1 do not hold and a reduction in the manufacturer's share of liability will lead to a less safe product. As another example regarding the conditions of Corollary 2, if the probability that all liability shifts to the manufacturer is a decreasing function of its care choice but the buyer views its care choice as a strong strategic substitute for the manufacturer's care, then reducing the manufacturer's share of liability will lead to a less safe product. These are just a few examples, but our point is that it is straightforward to identify many conditions under which tort reform leads to a less safe product.

Our final proposition characterizes the distributional impacts of reducing manufacturer liability for public harm.

Proposition 3: A reduction in the manufacturer's share of liability results in:
1. Lower combined expected per-unit costs of the consumer and manufacturer (i.e., expected per-unit market costs) and higher output.
2. Weakly higher expected per-unit and strictly higher total social costs.
3. Lower expected welfare.

Perhaps the most important implication of Proposition 3 is that reducing manufacturer liability increases the welfare of market participants, but shifts the burden of expected harm from the market to the public. On a per-unit basis, the reduction in the expected costs of the market participants is outweighed by the increase in the uncompensated expected public harm, *even if the product is safer*. In total, market participants are better off because their per-unit expected costs are lower and output is higher. In fact, in a competitive market, the increase in expected public harm from reducing manufacturer liability is strictly greater than the benefit to market participants. Thus, tort reforms that reduce manufacturer liability in competitive markets but do not otherwise completely assign liability to buyers unequivocally reduce expected social welfare.[4]

4 Conclusion

A surprisingly diverse array of US manufacturers enjoy immunity from liability for public harm as a result of tort reforms intended to reduce legal uncertainty; promote economic growth; and to incentivize care taking by buyers. We find that in theory product safety may improve as the manufacturer's share of liability for public harm falls. However, contingent liability is a necessary (though not sufficient) condition for this to occur. That is, there must be some probability that all liability shifts to the manufacturer, and this probability must be a function of its care choice. If liability is not contingent, and under a broad set of conditions when it is contingent, reducing manufacturer liability for public harm leads to less safe products. Regardless of whether reducing the manufacturer's liability share leads to more or less product safety, expected harm borne by the public strictly increases as a result and, in competitive markets, expected social welfare strictly declines. Hence, our results provide important caveats for pro-tort-reform intuition that a lower manufacturer liability share will, ceteris paribus, raise care taking by buyers and lead to higher social welfare.

[4]We noted earlier that Proposition 2 in Hay and Spier (2005) states that the second-best strict liability rule when the buyer does not face all liability pushes the residual liability to the manufacturer, thus maintaining $\delta^m + \delta^b = 1$. We confirm this finding in our context with the proof of part 3 of Proposition 3. Given incomplete liability shares, expected social welfare is monotonically increasing in the manufacturer's liability share. Given that the consumer's liability share is constant at $\delta^b < 1$, expected social welfare is maximized by increasing the manufacturer's share so that $\delta^m + \delta^b = 1$.

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Appendix

Proof of Proposition 1: Substitute (4) into the consumer's utility function (1) to obtain

$$U(q,x^b) = \int_0^q P(z)dz - \left[H(x^m,x^b)\delta^b(1-\rho(x^m)) + x^b + p\right] q + w. \tag{13}$$

We have already specified the consumer's choice of care, given the manufacturer's care, as eq. (5). Maximizing (13) with respect to q gives us the consumer's inverse demand for the product,

$$p = P(q) - H(x^m,x^b)\delta^b(1-\rho(x^m)) - x^b. \tag{14}$$

Now turn to the manufacturer. In a competitive equilibrium the price of the product is equal to the firm's expected marginal cost so that

$$p = H(x^m,x^b)(\delta^m + (1-\delta^m)\rho(x^m)) + x^m, \tag{15}$$

which is the representative manufacturer's inverse supply of the product. Combine this with the buyer's inverse demand (14) to obtain

$$P(q) = H(x^m,x^b)\left(\delta^m + \delta^b + (1-\delta^m-\delta^b)\rho(x^m)\right) + x^m + x^b. \tag{16}$$

Since the manufacturer chooses its level of care in anticipation of the buyer's choice of care and the equilibrium of the market, we may substitute $x^b = r^b(x^m,\delta^b)$ and (14) into the firm's profit function (3) to obtain

$$B(q,x^m) = \left[P(q) - H(x^m,r^b(x^m,\delta^b))\left(\delta^m + \delta^b + (1-\delta^m-\delta^b)\rho(x^m)\right) - x^m - r^b(x^m,\delta^b)\right] q. \tag{17}$$

Maximizing (17) with respect to x^m is the solution to

$$min_{x^m}\; H(x^m,r^b(x^m,\delta^b))\left(\delta^m + \delta^b + (1-\delta^m-\delta^b)\rho(x^m)\right) + x^m + r^b(x^m,\delta^b), \tag{18}$$

which gives us (6) of Proposition 1. The buyer then responds to this choice, $\widehat{x}^m$ with (7). Finally, substituting $\widehat{x}^m$ and $\widehat{x}^b$ into (16) gives us (8). □

Proof of Proposition 2: We begin the proof by establishing the following:

$$sgn\left(\frac{\partial \widetilde{H}}{\partial x^m}\right) = -sgn\left(\frac{\partial r^b}{\partial x^m} + 1 + \widehat{H}(1-\delta^m-\delta^b)\widehat{\rho}'\right); \tag{19}$$

$$sgn\left(\frac{\partial \widehat{x}^m}{\partial \delta^m}\right) = sgn\left(\widehat{\rho}' - \frac{(1-\widehat{\rho})}{\widehat{H}}\frac{\partial \widetilde{H}}{\partial x^m}\right). \tag{20}$$

Write the first-order condition for the manufacturer's care choice from (6) as

$$\left(\delta^m + \delta^b + (1-\delta^m-\delta^b)\widehat{\rho}\right)\left(\frac{\partial \widetilde{H}}{\partial x^m}\right) + \frac{\partial r^b}{\partial x^m} + 1 + \widehat{H}(1-\delta^m-\delta^b)\widehat{\rho}' = 0. \tag{21}$$

Eq. (19) follows directly from (21) because $\delta^m + \delta^b + (1-\delta^m-\delta^b)\widehat{\rho} > 0$. To establish (20), let $F(\widehat{x}^m, \delta^m)$ denote the left side of (21). Then,

$$\frac{\partial \widehat{x}^m}{\partial \delta^m} = -\frac{\partial F/\partial \delta^m}{\partial F/\partial x^m}.$$

Since $\partial F/\partial x^m > 0$ to satisfy the second-order condition for the choice of x^m, $sgn\,(\partial \widehat{x}^m/\partial \delta^m) = sgn\,(-\partial F/\partial \delta^m)$. From (21) calculate

$$-\frac{\partial F}{\partial \delta^m} = -(1-\widehat{\rho})\left(\frac{\partial \widetilde{H}}{\partial x^m}\right) + \widehat{H}\widehat{\rho}'. \tag{22}$$

Eq. (20) follows from $sgn\,(\partial \widehat{x}^m/\partial \delta^m) = sgn\,(-\partial F/\partial \delta^m)$, $\widehat{H} > 0$ and (22).

To complete the proof of Proposition 2 we note, from (9), that $\partial \widehat{H}/\partial \delta^m > 0$ if and only if $sgn\,(\partial \widehat{x}^m/\partial \delta^m) = sgn\left(\partial \widetilde{H}/\partial x^m\right)$. According to (19) and (20), this is accomplished by (12).□

Proof of Corollary 1: Suppose that $\widehat{\rho}' = 0$. Then, given $\widehat{\rho} \in [0,1)$, (20) becomes

$$sgn\left(\frac{\partial \widehat{x}^m}{\partial \delta^m}\right) = -sgn\left(\frac{\partial \widetilde{H}}{\partial x^m}\right),$$

which, because $\partial \widehat{x}^m/\partial \delta^m \neq 0$ and $\partial \widetilde{H}/\partial x^m \neq 0$, implies $\partial \widehat{H}/\partial \delta^m < 0$. Therefore, $\widehat{\rho}' \neq 0$ is a necessary condition for a reduction in the manufacturer's share of liability to result in lower expected public harm per unit of output. □

Proof of Corollary 2: Recall that $sgn\,(\partial \widehat{x}^m/\partial \delta^m) = sgn\left(\partial \widetilde{H}/\partial x^m\right)$ must hold if $\partial \widehat{H}/\partial \delta^m > 0$. Case 1 of the corollary involves $\partial \widetilde{H}/\partial x^m > 0$ and $\partial \widehat{x}^m/\partial \delta^m > 0$. In this case, (19) implies

$$\frac{\partial r^b}{\partial x^m} < -1 - \widehat{H}(1-\delta^m-\delta^b)\widehat{\rho}', \tag{23}$$

and (20) implies $\widehat{\rho}' > 0$. Eq. (23) and $\widehat{\rho}' > 0$ imply $\partial r^b/\partial x^m < -1$.

Case 2 of the corollary involves $\partial \widetilde{H}/\partial x^m < 0$ and $\partial \widehat{x}^m/\partial \delta^m < 0$. In this case, (19) and (20) imply

$$\frac{\partial r^b}{\partial x^m} > -1 - \widehat{H}(1-\delta^m-\delta^b)\widehat{\rho}', \tag{24}$$

and $\widehat{\rho}' < 0$, respectively. In turn, (24) and $\widehat{\rho}' < 0$ imply $\partial r^b/\partial x^m > -1$.□

Proof of Proposition 3: From Eq. (6) in Proposition 1, in equilibrium the manufacturer's care is chosen to minimize the manufacturer's and buyer's combined expected per-unit costs of selling and using the product (i.e., the expected per-unit market costs). Therefore, we can use the envelope theorem to calculate the marginal effect of δ^m on the right side of (6) as $\widehat{H}(1-\widehat{\rho}) > 0$, which reveals that the per-unit expected costs of selling and using the product fall as the manufacturer's liability is reduced. Since the consumer's demand for the product, $P(q)$, is strictly decreasing, output is higher. Thus, we have proven part 1 of Proposition 3.

To prove the second part of the proposition, we first show that the expected per-unit social cost of the product, $\widehat{SC} = \widehat{H} + \widehat{x}^m + \widehat{x}^b$, weakly increases as the manufacturer's liability share is decreased. Using $H(\widehat{x}^m, \widehat{x}^b)$ and (11), our goal is to show

$$\frac{\partial \widehat{SC}}{\partial \delta^m} = \left[\frac{\partial \widetilde{H}}{\partial x^m} + \frac{\partial r^b}{\partial x^m} + 1\right]\frac{\partial \widehat{x}^m}{\partial \delta^m} \leq 0. \tag{25}$$

Recall the first order condition for determining the manufacturer's choice of care, Eq. (21). Add and subtract $\partial \widetilde{H}/\partial x^m$ on the left side of (21), rearrange and collect terms to obtain

$$\frac{\partial \widetilde{H}}{\partial x^m} + \frac{\partial r^b}{\partial x^m} + 1 = \left[\frac{\partial \widetilde{H}}{\partial x^m}(1-\widehat{\rho}) - \widehat{H}\widehat{\rho}'\right](1-\delta^m-\delta^b). \tag{26}$$

Eqs. (20) and (26) imply

$$-sgn\left(\frac{\partial \widehat{x}^m}{\partial \delta^m}\right) = sgn\left(\frac{\partial \widetilde{H}}{\partial x^m} + \frac{\partial r^b}{\partial x^m} + 1\right),$$

which in turn implies (25). Note the very special case that (25) is zero if and only if $(\partial \widetilde{H}/\partial x^m)(1-\widehat{\rho}) - \widehat{H}\widehat{\rho}' = 0$. Now, recall from part 1 of this proposition that output strictly increases as the manufacturer's share of liability is reduced. Expected total social costs strictly increase because per-unit expected social costs weakly increase and output strictly increases.

To prove the final part of the proposition, first denote expected social welfare (2) evaluated at the equilibrium described in Proposition 1 as $\widehat{SW}$; that is,

$$\widehat{SW} = \int_0^{\widehat{q}} [P(z) - \widehat{H} - \widehat{x}^m - \widehat{x}^b] dz. \tag{27}$$

Differentiate (27) with respect to δ^m to obtain

$$\frac{\partial \widehat{SW}}{\partial \delta^m} = \left[P - \widehat{H} - \widehat{x}^m - \widehat{x}^b\right]\frac{\partial \widehat{q}}{\partial \delta^m} - \int_0^{\widehat{q}} \left[\frac{\partial \widetilde{H}}{\partial x^m} + \frac{\partial r^b}{\partial x^m} + 1\right]\frac{\partial \widehat{x}^m}{\partial \delta^m} dz. \tag{28}$$

The second term on the right side of (28) is non-negative from part 2 of the proposition. The first term is the change in expected social welfare that is due to the increase in the equilibrium quantity of the good as the manufacturer's liability is reduced. To sign the first term of (28), recall that the equilibrium quantity is determined by (8). Subtract H from both sides of (8) and collect terms to obtain

$$P - \widehat{H} - \widehat{x}^m - \widehat{x}^b = -\widehat{H}(1-\delta^m-\delta^b)(1-\widehat{\rho}). \tag{29}$$

The right side of (29) is strictly negative as long as liability is incompletely assigned, therefore

$$P - \widehat{H} - \widehat{x}^m - \widehat{x}^b < 0. \tag{30}$$

Part 1 of the proposition reveals that output increases with a reduction in the manufacturer's liability share. Combining $\partial \widehat{q} / \partial \delta^m < 0$ and (30) reveals that the first term of (28) is strictly positive. Since the second term is non-negative, expected social welfare declines as the manufacturer's share of liability for public harm is reduced. $\square$