Shared Liability and Excessive Care

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Extensive literature has shown that assignment of liability for a single harm to multiple injurers undermines incentives for optimal care. As each potential injurer anticipates bearing only a fraction of the harm, incentives to take precautions are often diluted. The dilution-of-liability concern has led theorists to propose sophisticated apportionment rules to restore optimal incentives. This Article demonstrates, however, that shared liability also gives rise to the converse risk, namely, it induces injurers – whether subject to negligence or strict liability – to invest *excessively* in care. Furthermore, unlike its extensively analyzed counterpart, the risk of excessive care arises under any apportionment regime. While apportionment rules cannot eliminate the problem of excessive care, we suggest other means by which the problem can be addressed.

1. INTRODUCTION

A common intuition suggests that if liability is spread among multiple injurers, its capacity to shape individual incentives gradually dissolves. Knowing that if harm occurs liability will be shared, each injurer expects to bear only a fraction of the victim's harm. Such limited liability, so the argument goes, undermines injurers' incentives to invest in care, particularly when the number of potential injurers is large. Accordingly, legal scholarship has long contended that tort liability may fail to induce multiple injurers to take sufficient care (Keeton and Prosser, 1984). As injurers only internalize the portion of the harm for which they bear liability, their incentives are diluted (*see*, *e.g.*, Levmore, 1986; Shavell, 1987; Harel and Jacob, 2002; Jacob, 2009; Tuch, 2010; Dillbary, 2013).

Against this backdrop, this Article argues that the conventional analysis of multiple injurers' liability, which largely focuses on the dilution problem, is in an important sense incomplete. While dilution-of-liability theory underscores the possibility of insufficient care, shared liability also produces the converse problem, namely, incentivizing *excessive* care. Both departures from optimal outcomes, although opposite in their respective effects, arise from coordination failures.

Whether injurers are likely to take excessive or insufficient care depends on the manner in which their conjoined efforts affect the probability of harm. The risk of insufficient care, identified in the literature, arises in "alternative care" cases, *i.e.*, cases where injurers' precautionary efforts function as *substitutes*.[1] In such cases, when one injurer takes precautions, other injurers' precautions become *less* effective in preventing the harm.[2]

Injurers consequently may seek to free-ride on the precautionary efforts of others. Moreover, each may reason that even if no one acts, liability will be spread sufficiently thinly among them, so that the individual share of liability will be lower than the cost of care.

Multiple-injurer cases, however, also consist of a second category. In "joint-care" cases, injurers' precautionary efforts are *complements*. When one injurer takes precautions, other injurers' precautions become *more* effective in preventing the harm.[3] It is in such cases that tort liability induces over-investment in precautions. We show that this concern arises under both negligence and strict liability, and may emerge under any level of complementarity.

The problem of excessive care may emerge in somewhat different form under each of the two liability regimes. In the domain of negligence, injurers' incentives to over-invest arise from the conventional application of the Hand formula. When courts examine negligence, they consider the precautions that the defendant *failed* to take.[4] As globally optimal levels of care are often difficult to identify, courts inquire whether the defendant could have taken an additional cost-effective precaution, but failed to do so. Thus, to establish negligence, a plaintiff must point to a "precaution untaken, which, if taken, would have had a greater marginal benefit than its marginal cost" (Brown, 1998). The untaken-precaution approach has been widely endorsed by commentators as a means to simplify the negligence determination without loss of analytical accuracy.[5]

We show that this conventional application of the Hand formula leads to an equilibrium in which injurers take excessive care. Particularly, under the formula, such incentives arise when care investments include some component of fixed cost. Over-investment then emerges as one of two equilibria within a setting akin to a “stag-hunt” game. Both equilibria carry attributes that draw the parties to them: while the efficient equilibrium is “payoff dominant”, i.e., maximizes the injurers’ joint (and individual) payoffs, the inefficient one is “risk dominant,” i.e., minimizes the strategic risk that each injurer faces. As suggested by a broad game-theoretic literature, and supported empirically, both equilibria are realistic and likely outcomes of the strategic interaction.[6]

Under strict liability, excessive care may arise in similar form (i.e., as one equilibrium within a stag hunt setting), but could also arise as a unique equilibrium. Furthermore, under strict liability, excessive care arises regardless of whether care investments include a fixed cost component. Thus, in an important sense, the prediction of excessive care is more robust under strict liability. However, in a different sense, the problem is more pervasive under negligence. We show that under negligence the problem arises irrespective of the precautionary technology. In contrast, under strict liability, it arises when precautions leave a low “residual risk”, namely when they eliminate the risk of causing the harm, or substantially diminish it.[7]

Existing scholarship concerned with the problem of dilution of liability has largely focused on the role of apportionment rules as means of restoring optimal incentives. Conversely, the present analysis demonstrates that manipulation of the apportionment regime cannot cure the problem of excessive care. An apportionment rule comes into play only when multiple injurers are jointly liable for the harm. But if a party invests excessively, she is often able to avoid liability entirely. Thus, if one believes that her counterparty intends to over-invest, then the content of the apportionment rule may have little impact on her own expected liability.

As modification of apportionment rules cannot resolve the problem of excessive care, we suggest alternative means of contending with the problem. First, we propose that the law recognize a new defense against a tort action, to which we refer as the "excessive-care defense." The purpose of the defense is to sever the link between one injurer's choice of excessive care and other injurers' exposure to liability. Thus, under a negligence action, if an injurer can show that her precaution became cost-effective only because others have taken excessive care, then she would be exempt from liability. Under strict liability, if she can show that others have taken excessive care, she would be entitled to share liability with them, as if they had taken optimal care and caused the harm jointly with her. By assuring injurers that they will not bear greater liability due to other injurers' excessive care, the defense will remove the strategic risk driving the incentive to over-invest. Second, we suggest that the law can reduce the risk of excessive care by facilitating coordination among injurers. We show that fundamental rules in both contracts and torts discourage such coordination. It follows that amending those rules can be conducive to incentivizing optimal behavior.

Since shared liability raises both a problem of excessive care and a problem of insufficient care, an ideal regime would address both concerns simultaneously. Accordingly, we propose a new mechanism – which we call the "Efficient Strict Liability" rule – whose purpose is to instate optimal incentives from both perspectives. The suggested rule provides that if some injurers were negligent, liability would be shared exclusively among them; and if none of them were negligent, liability would be shared among all injurers who caused the harm. This two-prong mechanism is shown to remove the incentive to under-invest, and when combined with the "excessive-care defense," removes the incentive to over-invest as well.

Excessive care has long been a major issue of concern among practitioners and legislators. Among all tort reforms, the rules governing multiple injurers have been the most common target for legal modification, with nearly 40 states amending their laws in this domain.[8] The main focus of states' reforms has been on abolishing the common-law regime of joint-and-several liability, and replacing it with the more injurer-friendly regime of several liability. A central justification for this change was the perception that joint-and-several liability induces excessive care and over deterrence of desirable activities, by making injurers responsible for harm caused by fellow injurers (particularly when the latter are insolvent). A similar reform, based on a similar premise, has been considered at the federal level as well.[9]

While it remains to be seen whether the repeal of joint-and-several liability lowers the burden on desirable activities, this Article suggests a different cause for multiple injurers' incentives to over-invest in care – the failure of coordination. These incentives arise whether liability rules retain the common law regime of joint-and-several liability, or opt for the more modern regime of several liability. Likewise, they do not depend on the rule of apportionment, or the risk of injurers' insolvency. The analysis thus offers a new approach to alleviating the potential for excessive care, and to enhancing social welfare.

Related Literature. As noted, the literature on multiple injurers has been mostly concerned with the risk of insufficient care. Landes and Posner (1980, 1987) and Shavell (1987) laid out the fundamental analysis. Subsequent literature examined how to best design apportionment rules in terms of both equity and efficiency (Rizzo and Arnold, 1980, 1986; Kaye and Aickin, 1984; Feess and Hege, 1998, Kornhauser and Revesz, 1989, 1995; Ferey and Dehez, 2016).[10] More recently, Guttel and Leshem (2014) and Leshem (2017) suggested that shared liability can induce excessive care if injurers are strictly liable. In line with prior literature, they too investigated the desirable features of an apportionment rule that could restore optimal incentives.[11]

The present analysis demonstrates that excessive care arises not only under strict liability, but also under negligence – which occupies the lion's share of the tort landscape. Moreover, as noted, it demonstrates that even an attentive design of apportionment rules cannot in fact resolve the problem. The apportionment rule is invoked when liability is shared. Yet, under both strict liability and negligence, investment in care often removes the risk of liability entirely, either by preventing individual causation, or – in the case of negligence – by rendering an investing party "non-negligent." As the apportionment rule affects payoffs only conditional on the imposition of liability, it has limited bearing on the incentive to take excessive care and the strategic risk underlying it.

The structure of the Article is as follows. Part II discusses an example, offering an intuition of the excessive care problem. Part III presents a formal analysis of the excessive care problem, under both a discrete model and a continuous one. Part IV considers normative implications, including a proposal for the adoption of a new defense under tort law (to which we refer as the "excessive-care defense"). Finally, Part V concludes. All proofs are relegated to the Appendix and to a Supplementary Materials.

2. EXAMPLE

To gain quick insight into the argument, consider the following simple example in which injurers choose whether to take care under a negligence regime.

> Two factories are situated in the vicinity of a lake. While both emit pollutants as part of their production process, each can install a filter that would prevent its pollutants from reaching the water. Each filter costs 6, and the social cost of contamination is 10.

Initially suppose that for contamination to occur, a critical mass of pollutants needs to be present in the water. Hence, if only one factory discharges pollutants, no harm is done; but if both factories discharge pollutants, then the critical mass is reached and contamination occurs. As a single filter is enough to prevent contamination, the example is one of alternative care (or substitute precautions). Since the cost of a single filter is lower than the harm (6<10), it is desirable that a single filter be installed. However, if each factory faces liability of merely half of the harm when harm occurs (5 out of the 10), neither has an incentive to spend 6 on a filter. The unique equilibrium is therefore one in which injurers under-invest.

But now consider the same example, with the sole variation that the critical mass is reached even when a single factory discharges pollutants. In this case, in order to prevent contamination, *both* factories must install filters. The example is thus one of joint-care (or complementary precautions). From a social perspective, prevention is now undesirable, as the cost of prevention (12) exceeds the cost of harm (10). Nevertheless, in this case both factories may be induced to install the filters. In fact, there are two equilibria in the game:

In one equilibrium, both refrain from care (as the cost of the untaken precautions exceeds the harm, neither factory will be deemed negligent). In the other equilibrium, both factories install the filter (if one factory installs the filter, the other's best response is to do the same for then it pays 6 rather than 10). Thus, contrary to the case of alternative care, the threat of liability may now induce the factories to over-invest.

As the untaken-precaution approach is a feature of negligence, one might surmise that the problem could be avoided by shifting to strict liability. However, the problem persists under strict liability, and in some cases it may even intensify. The example considered above produces the same stag hunt structure under strict liability. Namely, if one factory refrains from care, the other prefers to refrain as well: since liability is then shared, each factory expects to bear a cost of 5, which is less than the cost of precautions (6). However, if one installs a filter (thereby avoiding the discharge of pollutants), the other will wish to follow suit, as otherwise it will face liability for the entire harm (a cost of 10).

In other cases, however, strict liability may also yield excessive care as a unique equilibrium. To see the possibility, suppose alternatively that the factories' respective costs of care are 4 and 8 (rather than 6 for each). As the overall cost of care (12) exceeds the harm (10), optimal behavior still requires that neither install a filter. However, notice that in this case, installing a filter is a dominant strategy for the factory whose cost is 4: it prefers to do so regardless of the other factory's choice, as its cost of care (4) is always lower than its liability cost (5 or 10, depending on the other factory's choice).[12] As the first factory installs a filter, the second responds by doing the same (thereby incurring 8 in care rather than 10 in liability). Hence, a unique equilibrium is formed, in which investment in care is excessive.[13]

Note that the factories' incentives to take excessive care are independent of the apportionment rule. If one factory installs the filter, it is *always* in the interest of the other to follow suit. This is so, because by installing a filter, a factory severs its causal connection to the harm, thereby precluding its potential liability. Hence, the apportionment rule cannot eliminate the incentives for excessive care in such a setting. As it applies only when *both* injurers are liable, its prescribed allocation is irrelevant when one injurer escapes liability entirely through investment in care.

More generally, the problem of excessive care arises independently of the apportionment rule, because care often allows potential injurers to avoid liability *altogether*. This may occur (as in the above example) when an injurer's investment severs her causal relation to the harm. It also occurs under negligence, when care renders the investing party "non-negligent" and therefore non-liable for the harm. As investment often precludes liability, and as the apportionment rule applies only when both injurers are liable, the problem cannot be solved merely by modifying the rule.

3. MODEL

The discussion below formally examines the excessive care problem under both strict liability and negligence. Part A begins with a discrete model, generalizing the principles discussed above within the context of n players who make a binary choice between care and no care. Part B then proceeds to examine a continuous case, in which two players choose from a continuous range of care investments.

A. Discrete Case

Consider n players, $N = \{1,2, \dots n\}$, who simultaneously engage in an activity that may result in a (single) harm, which we normalize to 1. Each player must choose a precautionary strategy $s_i \epsilon \{0,1\}$, where $s_i = 0$ corresponds to no-care and $s_i = 1$ corresponds to care. If player i chooses care, she bears a cost of $c_i > 0$. For each S⊆N, let $s \in \{0,1\}^N$ denote a strategy profile in which members of S choose care and those outside of S choose no-care. Let $s^c = 1_n = (1, \dots ,1)$ denote the profile where all players take care and $0_n = (0, \dots ,0)$ the profile in which no one takes care.

The precautionary technology is given by a function $q: \{0,1\}^N \to [0,1]$, representing the probability of harm. We assume that q is declining in its argument, i.e., that if $S' \subset S$ then $q(s') > q(s)$. The precautionary technology is said to exhibit "residual risk" if $q(s^c) > 0$, and "no residual risk" if $q(s^c) = 0$. Social cost is given by $q(s) + \sum_i c_i \cdot s_i$, and thus the socially optimal profile s^* is the profile satisfying $s = argmin_s\{q(s) + \sum_i c_i \cdot s_i\}$. We assume that the underlying problem is generic in the sense that the social cost differs across all profiles, implying that the socially optimal profile is unique.

Let $\omega \in \Omega$ denote a random state of the world and let $D(s, \omega): s \times \Omega \to \{0,1\}^N$ denote the profile of realized causation as a function of players' care decisions and the state of the world, where the number 1 corresponds to players who caused the harm, and the number 0 to those who did not cause it. Player i's designated value in $D(s, \omega)$ is denoted $D_i(s, \omega) \to \{0,1\}$. We note that causation refers not only to activities that directly cause harm, but also to cases in which one player's choice of care affects other players' causation. We further assume that harm can only be caused by players, rather than by nature alone.[14]

The apportionment rule is a function $\lambda_i\big(s, D(s,\omega)\big) = \lambda_i\ (s,\omega)$ specifying a liability share for player i, which depends on the profile of care decisions and the realized state of the world. In line with conventional principles, we assume that $\sum_i \lambda_i(s,\omega) \leq 1\ \forall\omega, s$ (i.e., total liability never exceeds the harm), and that if $D_i(s,\omega) = 0$ then $\lambda_i(s,\omega) = 0$ (i.e., liability is not imposed without causation). We denote by $\lambda_i(s)$ the expected liability of i under the profile s, conditional on harm. We denote by $\lambda(s)$ the vector $\big(\lambda_1(s), \dots, \lambda_n(s)\big)$. We henceforth treat $\lambda_i(s)$ as one of the model's primitives. However, whenever imposing conditions on $\lambda_i(s)$, we explain how they can be derived from the model's more fundamental building blocks, i.e., the causation profile $D(s,\omega) = (D_1, \dots, D_n)$, the set of states of the world Ω and the probability of harm $q(s)$).

In the analysis that follows we characterize the scope of the problem of excessive care. We begin with strict liability, showing that the problem arises for any level of complementarity (Proposition 1), and that in some cases it can arise as a unique equilibrium (Proposition 2). We then demonstrate that excessive care arises under negligence as well, again for any level of complementarity (Proposition 3). Finally, we discuss the general conditions under which excessive care is likely to emerge.

We note that the model importantly differs from related models in the tort literature in that it does not restrict the technology of care, i.e., the form in which the probability of harm depends on players' care decisions. In particular, it does not rely on a weakest-link property, under which failure of care by a single player necessarily results in harm.

1. Strict Liability

Under strict liability, players are liable for any harm caused, and liability equals the harm. If harm is caused by a single injurer, then she bears liability alone. If harm is caused by multiple injurers, then liability is apportioned among them, such that $\sum_i \lambda_i(s,\omega) = 1 \ \forall\omega$. It is reasonable to assume the following conditions on the expected liability borne by each potential injurer j:

(C1) $\lambda_j(s_{-j}) > \lambda_j(s)$

(C2) If $S' \subset S$, then for every j in $N - S$, $\lambda_j(s) > \lambda_j(s')$

(C3) $\lambda_i(s^c_{-j}) = 1$

Condition (C1) provides that, given harm, j's expected liability is higher when choosing no-care than when choosing care, regardless of the identity of other players who have chosen care. Note that this condition can be derived as a result under a milder assumption that care by player j reduces the probability that j will cause the harm. Condition (C2) provides that if j chooses no-care, then her expected liability given harm rises when more of the other players have chosen care. This is because, when other players are less likely to cause harm, j's expected liability if he causes the harm, rises. Note that this assumption requires that no player can free ride on the precautionary efforts of other players, in the sense that other players' precautions cannot reduce the player's own probability of causation. Finally, (C3) is satisfied if precautions leave no residual risk, i.e., if $q(s^c) = 0$.[15] We show that under strict liability, excessive care emerges when the residual risk is sufficiently small, i.e., when $\lambda_j\left(s_{-j}^c\right)$ is close to 1. Accordingly, in the analysis that follows, we generally relax (C3) by requiring that the residual risk merely be “small”.

Note that although (C1)-(C3) are framed in terms of expected liability, they are easy to derive from the primitives. Specifically, (C1) holds when precautions reduce an individual’s probability of causing the harm. (C2) follows from the no-free-riding assumption, which is an assumption on primitives. Finally, (C3) simply follows from a condition on $q(s)$.

We next show that when the residual risk is small, excessive care emerges under any degree of complementarity. We emphasize that excessive care emanates from players' strategic considerations, rather than from the restriction of players' domain of possible actions, arising from the binary nature of their choice. We begin by stating the following lemma.

Lemma 1. If

$$\sum_i q(s_{-i}^c) > q(0_n) \tag{1}$$

and the residual risk is sufficiently small, then there exists a vector of costs $(c_1, \dots c_n)$ for which excessive care is obtained as a Nash equilibrium.

Proof. See Appendix. ■

Note that condition (1) conveys the property that the value of the last player’s investment exceeds the value of the average player’s investment (this could be observed by multiplying both sides of (1) by $\frac{1}{n}$). While this property holds whenever precautions are complements (as demonstrated in Lemma 2 below), it is a somewhat weaker requirement, as it essentially requires that precautions satisfy complementarity only for the last player.

To establish the relation between complementarity and condition (1) formally, we begin by defining the concept of complementary precautions. With a slight abuse of notation, we denote by $q(S)$ the probability of harm when all members of S took care and all other player did not.

Definition (Complementary Precautions). Precautions are complements if for every S' and S such that $S' \subset S$, and for each $i \epsilon N - S$,

$$q(S') - q(S' \cup \{i\}) < q(S) - q(S \cup \{i\}) \tag{2}$$

Lemma 2. If precautions are complements and the residual risk is sufficiently small, then (1) must hold.

Proof. See Appendix.■

Proposition 1. Under strict liability, if precautions are complements, and the residual risk is sufficiently small, then there exists a vector of costs $(c_1, \ldots c_n)$ for which excessive care is obtained as a Nash equilibrium. The existence of such an equilibrium does not depend on the apportionment rule or on the degree of complementarity.

Proof. The result follows directly from the combination of Lemmas 1 and 2. ■

Comments.

1. The result of excessive care is chiefly driven by the complementarity of precautions. As each player's investment raises the value of investments by other players, one player's decision to invest excessively triggers similar behavior by others.
2. Note that the incentive to invest excessively arises regardless of the apportionment rule. When all players but one choose care, the player choosing no-care bears liability alone ($\lambda_j(s_{-j}^c) = 1$). Hence, the criteria of apportionment (applicable when more than one injurer is liable) have no effect on incentives. The conditions under which excessive care emerges in equilibrium are therefore unaffected by the rule. The same logic applies if residual risk is positive, but sufficiently small. This in turn implies that the problem of excessive care cannot be generally cured by way of amending the rule.
3. When the residual risk is significant, incentives to over-invest may no longer be sustained. A high residual risk implies that care is less effective in preventing the harm. Consequently, the incentive to invest weakens, and excessive care is less likely to emerge. For an example illustrating the possibility that high residual risk will prevent excessive care from arising, see Supplementary Materials.
4. As can be straightforwardly demonstrated, excessive care may arise alongside an equilibrium of efficient care. To illustrate, consider a two-player example, in which a player choosing care does not cause harm, and a player choosing no care causes the harm with probability $\frac{7}{8}$. Thus, $q(0,0) = \frac{63}{64}$, $q(0,1) = q(1,0) = \frac{7}{8}$ and $q(1,1) = 0$. The apportionment rule provides that $\lambda_1(0,1,\omega) = \lambda_2(1,0,\omega) = 1$ and that $\lambda_1(0,0,\omega) = \lambda_2(0,0,\omega) = \frac{1}{2}$. Further assume that $c_1 = c_2 = \frac{3}{4}$. Hence, no-care is

a best response to no-care (as $\frac{3}{4} > \frac{1}{2} \cdot \frac{63}{64}$) and care is a best response to care (as $\frac{3}{4} < \frac{7}{8}$). While the former equilibrium is efficient, the latter involves excessive care.

5. Incentives to invest may be affected by the prospect of insolvency. Clearly, insolvent players will invest less, as they will no longer be deterred by the threat of liability. Solvent players, for their part, will tend to invest more. As they will bear a greater share of the liability (due to the exemption of their insolvent counterparts), their investment will tend to increase. Thus, with respect to solvent players, the problem of excessive care will be exacerbated.[16]

We next wish to show that when the last player's investment is characterized by a substantial degree of complementarity, excessive care may arise as a *unique* equilibrium under strict liability. We begin by defining the concept and then proceed to establish the result.

Definition (Strong δ Complementarity). Technology q is characterized by strong δ complementarity if $q(s_{1,2,\ldots,k}) > 0$ for $k < n$, and $1 > \frac{q(s_{1,2,\ldots,k})}{q(s_{1,2,\ldots,k-1})} > 1 - \delta$ for all $k < n$.

Intuitively, the degree of "δ complementarity" measures the extent to which the collective effort of all n players is vital for the prevention the harm. The lower the value of δ, the more critical is the marginal contribution of the n'th player. In the extreme case, in which $\delta = 0$, the probability of harm cannot be reduced unless all n players join in the effort. In that case, precautions are perfect complements (i.e., a weakest-link setting.).

We can now summarize the results within the following proposition.

Proposition 2. If q satisfies the condition of strong δ complementarity for a sufficiently small δ, and the residual risk is small, then there exist a cost profile $c_1, \dots, c_n$ for which the underlying game has a *unique* equilibrium, in which care is excessive.

The proof of proposition 2 is constructive, in the sense that we specify a cost vector inducing a unique equilibrium with excessive care. The construction generates a game that is dominant solvable (i.e., producing a unique equilibrium through iterative elimination of dominated strategies) with respect to some ordering of the players. In particular, it is shown that care is a dominant strategy for the first player in the ordering, and that it then becomes a dominant strategy for each subsequent player, given that all players preceding him in the ordering choose care as well. This construction is similar to the technique used by Winter (2004) and Halac, Kremer and Winter (2020). For the complete proof of Proposition 2, see Supplementary Materials.

2. Negligence

As discussed above, we consider a negligence regime following the "untaken-precautions" approach. We formally define that regime as follows:

Definition (Negligence under the "Untaken-Precautions" Approach). Let $s' = (s'_1, \dots s'_n)$ denote the profile of strategies actually taken, and let $\left(\sigma_1(s'), \dots, \sigma_n(s')\right)$ be the profile minimizing social cost under the constraint that $\sigma_i(s') \geq s'_i$ for all i. Then player i is considered negligent if $\sigma_i(s') > s'_i$. A player accordingly bears liability if she is negligent, and if her negligence caused the harm (i.e., if but for her negligence, she would not have caused it). Thus, in particular, if all players other than i play the profile s_{-i}, the probability that i's negligence will cause the harm is $q(s_{-i}, 0) - q(s_{-i}, 1)$.[17]

As explained above, legal scholarship has endorsed the untaken-precautions approach for its limited informational demands. By focusing merely on the precautions that the parties *failed* to take, courts are relieved from the burden of identifying the global optimum. Accordingly, courts only examine whether an untaken precaution exists that would have reduced expected harm cost-effectively.

Proposition 3. If precautions are complements and a negligence regime applies, then there exists a cost profile for which excessive care is obtained as a Nash equilibrium. The result does not depend on the apportionment rule, on the level of complementarity, or the magnitude of the residual risk.

Proof. See Appendix.■

Comments

1. Unlike the case of strict liability, residual risk does not limit the incidence of excessive care under negligence. Since care releases injurers from liability entirely, the presence of residual risk does not dilute the incentive to invest. Hence, from this perspective, the scope of the problem is broader under negligence than under strict liability.

2. Relatedly, the result is also independent of the apportionment rule. This is because whenever a number of players are deemed negligent (under the untaken-precautions approach), their aggregate cost of care must be lower than the full cost of liability. Hence, regardless of the apportionment rule, there must be at least one player for whom the cost of liability exceeds the cost of care, in which case that player is better off choosing care. As this reasoning can be repeated iteratively for the remaining group of negligent injurers, it follows that in equilibrium all players prefer choosing care to being considered negligent (Landes and Posner 1980). Thus, regardless of the apportionment rule, if one player expects to be deemed negligent as a result of another player's excessive care, her best response is to choose care. Amending the rule is not a means by which the problem can be corrected.
3. Further note that under negligence efficient care is always an equilibrium as well. To see why, consider the socially optimal profile s^*, and an actually played profile s' in which all players but j behave as in s^*. It can readily be shown that j's incentive is to behave optimally as well. Namely, if $s_j^* = 0$, then j minimizes cost by choosing $s_j' = 0$, as he is then non-negligent, and therefore bears no liability whether he causes the harm or not. Alternatively, if $s_j^* = 1$, then j minimizes cost by choosing $s_j' = 1$. This is so because failing to choose $s_j' = 1$ implies that he will be considered negligent. Consequently, he will bear liability for the entire harm whenever his negligence causes the harm. As the probability that j's negligence will cause the harm is $q\left(s^*_{-j}\right) - q(s^*)$, choosing $s_j' = 0$ would be privately beneficial for j if and only if $c_j > q\left(s^*_{-j}\right) - q(s^*)$. But this condition cannot hold,

as it is inconsistent with the premise that s^* is socially optimal. As player j has no incentive to deviate, s^* is a Nash equilibrium.

4. We further note that if the court can directly observe the socially optimal profile (i.e., without basing its determination on the untaken-precautions approach), then excessive care does not emerge in equilibrium. The reason is simply that if no liability is ever imposed on players who take optimal care, then taking excessive care is a dominated strategy for all players. It follows that the problem of excessive care, as identified in Proposition 3, is fundamentally linked to the untaken-precautions approach, and to the informational problem underlying its adoption. For a discussion of the efficiency of negligence when courts observe the socially optimal profile, see Landes and Posner (1980), Shavell (1987), Schweizer (2016).
5. Similar to the case of strict liability, if some players are insolvent, then they will tend to invest insufficiently. However, contrary to the case of strict liability, solvent players are likely to respond by lowering their own investments. Given the complementarity of precautions, the decline in investment by insolvent players reduces the social value of investment by solvent ones. Accordingly, the negligence standard (applying the untaken-precautions approach) will require less of solvent players, allowing them to reduce their cost of care without facing liability.
6. Finally note that the condition for excessive care under negligence is stricter than under strict liability. This is because the premise that $\lambda_i(s_{-i}^c) = 1$, which holds under strict liability, can no longer be assumed under negligence. In particular, a player may bear no liability even when she is the sole cause of harm, because she may not be considered negligent.

3. Note on the Conditions in Which Excessive Care Arises

The analysis above demonstrates the existence of an excessive care equilibrium. However, in doing so it also conveys the conditions under which the phenomenon arises.

Recall that under strict liability, the problem emerges when $\sum_i q(s^c_{-i}) > \sum_i c_i > q(0_n)$ and provided that the residual risk is small. As excessive care is a byproduct of complementarity, its incidence is greatest when complementarity is perfect (i.e., a "weakest-link" setting, where $q(s) = 1$ for all $s \neq 1_n$ and $q(s^c) = 0$). Thus, if there is no residual risk and complementarity is perfect, $q(s^c_{-i}) = q(0_n) = 1$. The condition for excessive care then reverts to $n > \sum_i c_i > 1$, implying that the average cost of care can range anywhere from $\frac{1}{\mathrm{n}}$'th of the harm, to the full extent of the harm. The range is therefore very broad, and broadens as the number of players rises. Furthermore, when the above conditions are met, Proposition 2 establishes that excessive care may also emerge as a unique equilibrium, constituting the exclusive prediction of the game.

The range accordingly diminishes as the above conditions are relaxed. Namely, as residual risk rises upward, it narrows down from the left. The same occurs as complementarity weakens (i.e., $q(0_n)$ and $q(s^c_{-i})$ move away from 1). With that said, excessive care remains possible so long as precautions display any level of complementarity at all (see Lemma 2).

Under negligence, the conditions required for excessive care are similar, albeit not identical. Whereas the range is somewhat smaller than under strict liability (in particular, $\sum_i [q(s^c_{-i}) - q(s^c)] > \sum_i c_i > q(0_n) - q(s^c)$), its existence does not depend on the magnitude of the residual risk. Similar to the case of strict liability, the range is broadest when the residual risk is zero and complementarity perfect – in which case the average cost can vary between $\frac{1}{n}$'th of the harm and the harm in full. Moreover, the problem remains in place as long as precautions display any level of complementarity (see Proposition (3)). It should be noted, however, that under negligence (as opposed to strict liability) the excessive care equilibrium always arises alongside an efficient equilibrium. Hence, even when costs fall within the range, there is no certainty that the inefficient equilibrium will be selected.

B. Continuous Case

We next examine the phenomenon of excessive care under a model in which care investments are continuous. We find that the problem remains intact under strict liability, and that in some sense it even intensifies – as the equilibrium of excessive care is then always unique. Under negligence, however, the problem ceases to hold. We show that if players' care investments can be adjusted up to arbitrarily small increments, the excessive care equilibrium unravels. This suggests that for the problem to arise under negligence, precautions must include some component of fixed cost.

We consider two players $\{1,2\}$, who can each take a care level $x_i \geq 0$ to prevent a (single) harm of 1. For each player i we denote by $q_i(x_i)$ the probability that i will cause the harm, where $q_i(x_i) > 0$ for $x_i > 0$, $q_i'(x_i) < 0$ and $q_i''(x_i) > 0$. The cost of care for player i is given by $c_i(x_i)$ where $c_i'(x_i) > 0$ and $c_i''(x_i) < 0$. Harm occurs if at least one player causes it.

1. Strict Liability

Under a strict liability regime, liability equals the harm caused. If harm is caused by both players, then each player i bears a fraction $\gamma_i(x_i, x_j) \in (0,1)$ of the harm, where $\gamma_1(x_1, x_2) + \gamma_2(x_1, x_2) = 1$. We show that excessive care emerges under a broad class of apportionment rules. In particular, it emerges under constant apportionment (i.e., a sharing rule that is independent of players' investments, such as an equal division rule); and under apportionment favoring investment (e.g., the rule of "relative responsibility" adopted by the Restatement). We begin with the case of constant apportionment.

Proposition 4 (Excessive Care under Strict Liability – Constant Apportionment). Under a strict liability regime, the two-player model with complementarity and a constant apportionment rule yields a unique equilibrium of excessive care.

Proof. See Appendix. ■

Next consider the case in which the apportionment rule depends on players' levels of care. Let $e_i(x_i) = \frac{q_i'(x_i)}{q_i(x_i)}$ denote the elasticity of i's technology, and let $MRS_{\gamma_i} = \frac{\partial \gamma_i(x_i,x_j)}{\partial x_i} / \frac{\partial \gamma_i(x_i,x_j)}{\partial x_j}$ denote the marginal rate of substitution of $\gamma_i(x_i, x_j)$. The elasticity of i's technology represents the percentage decline in the probability of causing harm arising from a unit increase in investment. The marginal rate of substitution represents the increased investment that i must make in response to j's unit increase of investment, in order to keep the apportionment unchanged.

We now impose the following two conditions.

(1) $MRS_{\gamma_i} = \frac{e_i(x_i)}{e_j(x_j)}$

(2) $\frac{\partial^2 \gamma_i(x_i, x_j)}{\partial x_i \partial x_j} < e_i(x_i) e_j(x_j) \left(1 - \gamma_i(x_i, x_j)\right)$

Condition (1) requires that the marginal rate of substitution of $\gamma_i(x_i, x_j)$ equals the ratio of elasticities of the two technologies (which can also be interpreted as shadow prices of care). Condition (2) requires that the second derivative of $\gamma_i(x_i, x_j)$ is positive and large relative to the technology elasticities. We next show that if conditions (1) and (2) are met, players are induced to take excessive care. We then proceed to show that (1) and (2) support a large set of primitives, including the intuitive case in which apportionment is inversely related to each player's relative investment.

Proposition 4' (Excessive Care under Strict Liability – Variable Apportionment). Under a strict liability regime, if the two-player model with complementarity satisfies conditions (1) and (2) above, then excessive care is obtained as a unique equilibrium.

Proof. See Appendix.■

The following Corollary establishes that conditions (1) and (2) indeed support a large set of primitives, including the case in which a player's apportionment is inversely related to her relative investment in care.

Corollary 4' (Excessive Care under Strict Liability – Variable Apportionment). Assume that $q_i(x_i) = f(1 - x_i)$ and $\gamma_i(x_i, x_j) = \frac{f(1-x_i)}{f(1-x_i) + f(1-x_j)}$ where f is a twice differentiable and increasing function. Then under complementary precautions, strict liability yields a unique equilibrium of excessive care.

Proof. See Supplementary Materials. ■

2. Negligence

As in the discrete case, the negligence regime is defined according to the untaken-precautions approach. The definition is adjusted to the continuous case, as follows:

Definition (Negligence under the "Untaken Precautions" Approach – The Continuous Model) Let $(\hat{x}_1, \hat{x}_2)$ denote the profile of strategies actually taken, and let (x_1^e, x_2^e) be the profile minimizing social cost under the constraints that $x_i^e \geq \hat{x}_i$ for $i = 1,2$. Then player i is considered negligent if $x_i^e > \hat{x}_i$. A player accordingly bears liability if she is negligent, and if her negligence caused the harm.

We next show that in the continuous case, excessive care ceases to hold under a negligence regime. For purposes of the proposition below we assume that the vector space of care is compact (e.g., the square $[0, M] \times [0, M]$) and that the optimal levels of care are interior points of the set.

Proposition 5. Regardless of the values of $q_1(x_1)$, $q_2(x_2)$, $c_1(x_1)$ and $c_2(x_2)$, excessive care never arises under negligence.

Proof. See Appendix. ■

This result implies that when care can be tuned to an infinitesimal level, an unraveling dynamic diffuses the incentive to over-invest. Under a negligence regime, each player minimizes social cost given the level of care chosen by the other. Hence, the players face a game where one global function determines the incentives of both players to change their strategies. In such games (known as "potential games", see Monderer and Shapley (1996)), an equilibrium is obtained through a dynamic best response process, whereby each player optimizes his level of care in response to the level chosen by the other in an iterative fashion. This process converges to the global social optimum and forms an equilibrium. As this process of convergence hinges on players' ability to make arbitrarily small changes in their level of care, it does not characterize the discrete model. Thus, the combined message of the discrete and continuous models suggests that excessive care can arise under negligence, but only if precautions include some component of fixed cost.

4. NORMATIVE IMPLICATIONS

The problem of excessive care arises from the interdependence created between players' individual behavior and their exposure to liability. In joint-care cases, a player's duty to compensate the victim (under negligence) and the amount she must pay (under both negligence and strict liability) depend not only on her own precautionary decision, but also on the corresponding decisions of her counterparts. It is that linkage that drives the motivation to over-invest. Accordingly, countering the problem of excessive care requires the removal of this dependence.

Based on this observation, we delineate two main approaches to alleviating players' incentives to invest excessively. The first is to recognize an "excessive-care defense", whereby an injurer would be relieved of liability if establishing that the combined cost of precautions was excessive in relation to the risk. The second approach is to devise legal rules with attention to their effect on the likelihood of coordination among potential players. Because one is often induced to over-invest only due to concerns that others might do so, coordination may help overcome the problem of excessive care. We show, however, that current doctrine in both contracts and torts often discourages such coordination. Hence, amending the doctrine may serve to enhance efficiency.[18]

A. The Excessive-Care Defense

The first approach to contending with the problem of excessive care is to recognize a new defense, shielding injurers from liability when care is excessive. Under the "excessive-care defense," an injurer would be able to avoid liability by showing that the aggregate efforts required to avert the harm outweighed the victim's expected loss. Thus, in the context of the example considered in Section II, if one factory installed a filter while the other did not, the latter would establish a valid defense by showing that the combined cost of 12 exceeds the victim's expected losses of 10.

The defense may be applied in principle under both negligence and strict liability. We next discuss its precise definition and effect in each of the two regimes.

1. Negligence

Recall that under negligence, the problem of excessive care is a byproduct of the "untaken-precautions" approach, underlying the negligence determination. Courts reach a finding of negligence by identifying a cost-effective precaution that the injurer failed to take. However, as shown above, when precautions are complements, a player's precaution may become cost-effective only because another player has invested excessively. It is the threat of liability in such cases that drives the creation of an excessive care equilibrium. Thus, if an injurer can establish that her untaken precautions would not have been efficient but for her counterpart's excessive investment, then she ought to be offered a defense, and relieved of liability.

The suggested defense eliminates the incentive to over-invest by ensuring that the excessive precautions taken by one player do not expose her fellow players to greater liability. Once the strategic risk is removed, players revert to the efficient equilibrium in which none of them invests excessively, and none bears any liability.

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We next develop the argument within the context of the discrete model.[19] Denote by $SC(s) = q(s) + \sum_i c_i$ the total social cost under profile s. Accordingly, the defense can be defined as follows:

Definition (Excessive-Care Defense for Negligence). Under the Excessive-Care Defense for Negligence, injurer i is exempted from liability if for any profile s' with $s'_i = 1$, she is able to show that a profile s'' exists, in which $s''_i = 0$ and for which $SC(s') > SC(s'')$. If i is granted the defense, then the apportionment rule is determined by $\lambda(s_{-i}, 1, \omega)$. Thus, liability is apportioned among liable injurers as if injurer i was not negligent.

Note that this framing captures the incremental procedure underlying the untaken-precautions approach: to apply the defense, the defendant need not identify the global optimum. Rather, she must point to a socially superior profile, in which her individual designation is to take no-care.

Proposition 6. Under a negligence regime in which the excessive-care defense applies, the socially optimal profile is a unique Nash equilibrium.

Proof. See Appendix.■

2. Strict Liability

The defense may also apply under strict liability, albeit in a somewhat different form. Strict liability implies that injurers must compensate victims for their harm, even when they act efficiently. Accordingly, if an injurer successfully establishes the defense, its effect would not be to relieve her of liability in full, but rather to allow her to bring an indemnity suit against an over-investing party. Given indemnity, liability would be apportioned among the parties as if both invested optimally, and as if over-investing parties in fact caused the harm. In the context of our example, if under the efficient scenario both factories choose no care and share a liability of 10 equally, then the same apportionment would follow if a single factory over-invests, and harm is caused only by the other. This would be done by initially holding the non-investing factory liable for the entire 10, and then allowing her to recover 5 from the investing factory through an indemnity suit.

Note that applying the defense in the context of strict liability may involve a certain departure from conventional doctrinal principles. Subjecting the investing factory to an indemnity claim is tantamount to imposing liability on a party who did not cause the victim any harm. In effect, the investing factory faces liability not for the harm that it caused the victim (it did not), but rather for the harm that it caused *its fellow player*. The investing party is liable towards her fellow player for exposing her to greater liability than she would bear if both acted optimally. It is that externality that the indemnity suit is meant to internalize.

While the excessive-care defense removes the incentive to invest excessively, it does not treat a separate problem arising under strict liability, namely the possible incentive to *under-invest*. As acknowledged by the literature, the sharing of liability among multiple injurers may dilute their incentive to invest, as it keeps them from internalizing the full value of their investment (Shavell, 1987: 177-178). Thus, a complete solution to the incentive problem under strict liability must address not only the problem of excessive care, but also the potential problem of insufficient care.

To address both problems in tandem, we propose a novel legal regime, which we call the "Efficient Strict Liability Rule". The proposed regime combines the excessive-care defense (addressing the over-investment problem) with a mechanism to address the under-investment problem. We begin by establishing that the excessive-care defense removes the incentive to over-invest. We then proceed to demonstrate that the Efficient Strict Liability Rule indeed solves both problems simultaneously. We establish the results within the context of the discrete model. For derivation of the same results within the context of the continuous model, see Supplementary Materials.

We formally define the defense as follows.

Definition (Excessive-Care Defense for Strict Liability). Player j is entitled to the Excessive Care Defense for Strict Liability if there exists some player i with $s_i = 1$, and j

can establish that for any profile s' with $s_i' = 1$ there exists a profile s'' in which $s_i'' = 0$ and $SC(s'') < SC(s')$.

If j is entitled to the defense, then the apportionment rule is determined as follows: Let s^0 be a profile such that $s_k^0 = s_k$ for all $k \neq i$, and $s_i^0 = 0$. The apportionment of liability is now given by $\lambda_r(s^0, D_{-i}(s^0, \omega), 1)$ for all $r \in N$. Namely, the applied apportionment assigns liability, as if all players but i behaved as in the actual profile, while player i chose no care and caused the harm.

Proposition 7a. If a strict liability regime is applied alongside the Excessive-Care Defense for Strict Liability, then excessive care is never obtained in equilibrium.

Proof. See Appendix.■

As mentioned, the excessive-care defense removes the incentive to invest excessively, but does not resolve the separate concern which may arise under strict liability – the possible incentive to invest insufficiently. The Efficient Strict Liability Rule, which we consider next, seeks to tackle both concerns at once.

The suggested rule consists of two prongs. First, it provides that if any of the injurers causing harm were negligent, then the apportionment rule will assign liability only to them. Second, if none of the injurers causing harm were negligent, then liability will be apportioned among all injurers who caused the harm, including those who are treated as if they caused harm through the application of the defense. Notice that the rule retains the character of strict liability, as whatever choices players make, the victim is fully compensated for her harm.[20]

Definition (Efficient Strict Liability Rule)

(a) If harm is caused and one player or more are negligent, then liability is assigned only to the negligent players, according to some apportionment rule.

(b) If harm is caused and none of the players are found negligent, then liability is apportioned among all players who caused the harm, according to some apportionment rule (including those treated as if they caused the harm through the application of the Excessive-Care Defense for Strict Liability).

Proposition 7b. Under the Efficient Strict Liability Rule, the socially optimal profile is a unique Nash equilibrium.

Proof. See Appendix. ■

B. Facilitating Coordination

The excessive-care defense restores optimal incentives by protecting injurers who take optimal care from liability. An additional, more subtle approach in which the law can address the concern of excessive care, is to facilitate coordination among potential injurers. In a stag-hunt interaction, the equilibrium most favorable to the players is also the optimal one from a social point of view. Hence, if players can coordinate their actions, they share a mutual interest to pursue the socially optimal equilibrium.

Yet, legal doctrine in both contracts and torts discourages players from collaboration. Contracts to *restric*t precautions may be viewed as tantamount to “agreements to commit a tort." As such, they may be voided on grounds of public policy, and be impossible to enforce.[21] Lack of enforcement, in turn, implies that for all players, taking excessive care remains the risk-dominant strategy. Accordingly, the parties' interaction maintains the stag-hunt structure, keeping the incentive to over-invest intact.

Arguably, the parties might coordinate even without a binding contract. If all parties benefit from the selection of the socially optimal strategies, then perhaps even an unenforceable statement to choose them may be afforded some credibility. However, under strict liability, apportionment rules impede on such coordination as well.

Existing apportionment rules are often sensitive to *relative responsibility* or *relative causal contribution* to risk.[22] Structuring apportionment in this way implies that an injurer's liability depends not only on her own investment decision, but also on those of others. Keeping all else equal, each injurer prefers that others will invest less than she does, as that reduces her relative share of the burden. This property hinders coordination under strict liability. Given injurers' advantage when their investments in care exceed those of others, their (unenforceable) statements to refrain from care may not be credible.

To illustrate this point, consider again the example with the two factories. Now suppose, however, that if either factory (or both) pollutes the lake, a harm of 120 eventuates. Each factory can invest 45 in a filter, in which case its likelihood of polluting falls from 100% to 50%. Further suppose that if one factory installs a filter while the other refrains, and both pollute, the apportionment rule assigns the former (who chose care) only 1/3 of the harm, while assigning the second the remaining 2/3. Observe that care in this example is inefficient: while the combined cost of the filters is 90, their capacity to reduce the expected harm is merely 30.[23] Yet, as demonstrated in the matrix below, (Care, Care) and (No-care, No-care) are both Nash equilibria.

	Care	**No-care**
Care	(90,90) [24]	(65,100) [25]
No-care	(100,65)	(60,60)

Note that given the apportionment rule, coordinating a collaborative decision to refrain from acquiring the filters may be highly difficult to reach. Because the rule favors investing parties, a factory's commitment to refrain from care may not be credible. If one factory intends to choose care, it is in its interest to misrepresent that intention to the other. That is so, because if it is the only one choosing care, its liability share drops from 1/2 to 1/3 when both factories cause the harm. Hence, its promise to refrain from care will mean little: regardless of its actual intention, its statement, in and of itself, will carry little informational value (see Aumann, 1990).

The greater the apportionment rule's bias in favor of investing parties is, the more powerful an investing party's incentive to misrepresent its intention will be, and hence the more difficult coordination will become. Moreover, if the apportionment rule's bias extends beyond a certain threshold, then the (No-care, No-care) equilibrium may altogether disappear. In that case, choosing care becomes the players' *dominant* strategy – which further undermines the possibility of coordination. To see this, suppose that instead of an apportionment ratio of 1/3 – 2/3 (as in the previous example), the ratio is now altered to 1/5 – 4/5 in favor of the investing party. The payoff matrix is now given as follows:

	Care	**No-care**
Care	(90,90)	(57,108)[26]
No-care	(108,57)	(60,60)

In this example, (Care, Care) is a unique equilibrium. Note that the bias of the apportionment rule has transformed the problem from a “stag-hunt” into a “prisoner’s dilemma”. Accordingly, keeping a promise to refrain from care has now become a strictly dominated strategy. The possibility of coordination in this setting is therefore further curtailed.

In sum, legal rules can affect the prospects of successful coordination. The law can support the credibility of promises to refrain from excessive care by rendering such promises legally enforceable. Alternatively, it may enhance credibility by lowering the payoff emanating from misrepresentation. Apportionment rules may foster that objective by avoiding preferential treatment of parties who over-invest.

5. CONCLUSION

Alexander Hamilton in the *Federalist Papers* has cautioned against the peril of shared liability. In addressing the ineffectiveness of reputational incentives, he famously contended that “regard for reputation has a less active influence when the infamy of a bad action is to be divided among a number than when it is to fall singly upon one.” It is, as Hamilton suggested, an evitable outcome that “has been inferred by all accurate observers of the conduct of mankind; and the inference is founded upon obvious reasons.”[27]

Hamilton's observation, indeed echoed by many, emphasizes one implication of shared liability: the concern that incentives would be diluted. The present analysis suggests, however, that shared liability also raises the opposite concern. When subject to the threat of liability, injurers who anticipate sharing responsibility with others are incentivized to invest excessively in care. This concern arises whether liability is strict or premised on the conventional perceptions of fault.

The problem of shared liability is rooted in the linkage between one's behavior and the exposure of others to liability. In alternative-care cases, one's investment eases the burden on others, whereas in joint-care cases it increases it. Accordingly, care is potentially insufficient in the former case, and excessive in the latter. To restore optimal incentives, the nature of one's optimal action must be unlinked from the choices made by others. While previous literature on shared liability suggested that apportionment rules can be employed to create optimal incentives, the present analysis shows that the risk of excessive care is in fact immune to any apportionment regime. Yet this does not imply that the legal system cannot apply other means to address the problem. Such means may include changing the injurers' payoff matrix, and removing impediments to successful coordination.

Appendix

Proof of Lemma 1. We prove the Lemma by showing that if $\sum_i q(s^c_{-i}) > q(0_n)$, then there exists a cost profile $(c_1, \ldots, c_n)$ for which s^c is a Nash equilibrium in which care is excessive.

Initially note that if $\sum_i c_i > q(0_n) - q(s^c)$ then s^c yields excessive care. Moreover, s^c is a Nash equilibrium if $c_i \leq q(s^c_{-i})\lambda_i(s^c_{-i}) - q(s^c)\lambda_i(s^c)$ for all i.

Hence, a vector of costs satisfying both conditions exists if and only if:

$$\sum_i [q(s^c_{-i})\lambda_i(s^c_{-i}) - q(s^c)\lambda_i(s^c)] > q(0_n) - q(s^c) \quad \text{(A1)}$$

Observe, however, that $\sum_i \lambda_i(s^c) = 1$, and by (C3), $\lambda_i(s^c_{-i})$ is sufficiently close to 1. Hence, the LHS of $(A1)$ is sufficiently close to $\sum_i q(s^c_{-i}) - q(s^c)$. But as $\sum_i q(s^c_{-i}) > q(0_n)$ by assumption, (A1) must hold. ■

Proof of Lemma 2. Without loss of generality, arrange players by an identity ordering, referring to each by her respective position (i.e., players $1,2,3, \ldots, n$). We can now express the sum of players' marginal contributions to the prevention of harm as follows:

$$[q(s^c_{-1}) - q(s^c)] + [q(s^c_{-1,2}) - q(s^c_{-1})] + [q(s^c_{-1,2,3}) - q(s^c_{-1,2})] + \cdots$$

$$+[q(0_n) - q(s^c_{-1,2,\ldots,n-1})] = q(0_n) - q(s^c).$$

Note that the equality holds because the sum is telescopic.

Next suppose that players 1 and 2 flip positions, and consider the same sum with respect to the new ordering. We now have:

$$[q(s^c_{-2}) - q(s^c)] + \left[q\left(s^c_{-1,2}\right) - q(s^c_{-2})\right] + \left[q\left(s^c_{-1,2,3}\right) - q\left(s^c_{-1,2}\right)\right] + \cdots$$

$$+ \left[q(0_n) - q\left(s^c_{-1,2,\dots,n-1}\right)\right] = q(0_n) - q(s^c).$$

Consider now the ordering in which player i flips position with player 1 (in the original ordering). Thus,

$$[q(s^c_{-i}) - q(s^c)] + \left[q\left(s^c_{-i,1}\right) - q(s^c_{-i})\right] + \left[-q\left(s^c_{-i,1,2}\right) - q\left(s^c_{-i,1}\right)\right] + \cdots$$

$$+ \left[q(0_n) - q\left(s^c_{-1,2,\dots,n-1}\right)\right] = q(0_n) - q(s^c).$$

Proceed similarly by induction until n sums are obtained, with the last one being:

$$[q(s^c_{-n}) - q(s^c)] + \left[q\left(s^c_{-n,1}\right) - q(s^c_{-n})\right] + \left[q\left(s^c_{-n,1,2}\right) - q\left(s^c_{-n,1}\right)\right] + \cdots$$

$$+ \left[q(0_n) - q\left(s^c_{-1,2,\dots,n-1}\right)\right] = q(0_n) - q(s^c).$$

Since each of these n sums equals $q(0_n) - q(s^c)$, the mean of the n^2 terms in these n sums is $\frac{1}{n}[q(0_n) - q(s^c)]$.

Because q satisfies complementarity, the first term of each sum must be greater than each of the $n-1$ terms that follow. Hence the mean value of the first terms across all sums must be greater than $\frac{1}{n}[q(0_n) - q(s^c)]$. Note that the sum of these first terms is given by $\sum_i[q(s^c_{-i}) - q(s^c)]$ and their mean is thus $\frac{1}{n}\sum_i[q(s^c_{-i}) - q(s^c)]$. We therefore have $\frac{1}{n}\sum_i[q(s^c_{-i}) - q(s^c)] > \frac{1}{n}[q(0_n) - q(s^c)]$, or, $\sum_i q(s^c_{-i}) > q(0_n) + (n-1)q(s^c) > q(0_n)$, which is condition (1). ■

Proof of Proposition 3. As precautions are complements, $\sum_i[q(s^c_{-i}) - q(s^c)] > q(0_n) - q(s^c)$. Accordingly consider the profile of costs $c = (c_1, \dots, c_n)$ satisfying $\sum_i[q(s^c_{-i}) -$

$q(s^c)] > \sum_i c_i > q(0_n) - q(s^c)$. The inequality on the right-hand side guarantees that s^c involves excessive care. It hence remains to be shown that s^c is also a Nash equilibrium. To establish this, consider player j's incentive to deviate from s^c. Because $\sum_j c_j < \sum_j [q(s^c_{-j}) - q(s^c)]$, we can ensure that the vector c satisfies $c_j < q(s^c{}_{-j}) - q(s^c)$ for all j. This guarantees that if all players but j choose care, then it is socially efficient for j to choose care as well. It follows that (under the untaken-precautions approach), if j deviates, he will be considered negligent. Moreover, the probability that j's negligence will cause the harm is $q(s^c_{-j}) - q(s^c)$. As j will then be the only negligent player under s^c_{-j}, he will bear the entire harm when found liable. Hence, j's expected liability when choosing no care equals $\left(q(s^c_{-j}) - q(s^c)\right)$ as well. But as $c_j < q(s^c{}_{-j}) - q(s^c)$ he will be better off choosing care. ■

Proof of Proposition 4 (Excessive Care under Strict Liability – Constant Apportionment). The social cost is given by the expected harm, plus the cost of care:

$$SC(x_1, x_2) = [1 - (1 - q_1(x_1))(1 - q_2(x_2))] + c_1(x_1) + c_2(x_2) \tag{A2}$$

The social planner thus minimizes (A2), or equivalently maximizes:

$$SW(x_1, x_2) = -SC(x_1, x_2) = [-1 + (1 - q_1(x_1))(1 - q_2(x_2))] - c_1(x_1) - c_2(x_2) \tag{A3}$$

where $SW(x_1, x_2)$ denotes social welfare.

Denoting by C_i the total cost of player i, each player minimizes his expected liability plus his cost of care. Liability equals the entire harm when player i causes harm alone, and a constant portion γ_i when causing it jointly with player j:

$$C_i(x_i, x_j) = q_i(x_i)\left(1 - q_j(x_j)\right) + \gamma_i q_i(x_i) q_j(x_j) + c_i(x_i)$$

Equivalently, player i can be viewed as maximizing private value, given by:

$$V_i(x_i, x_j) = -C_i(x_i, x_j) = -q_i(x_i)\left(1 - q_j(x_j)\right) - \gamma_i q_i(x_i) q_j(x_j) - c_i(x_i)$$

Note that $\frac{\partial^2 SW}{\partial x_1 \partial x_2} = q_1'(x_1) q_2'(x_2) > 0$ and $\frac{\partial^2 V_i}{\partial x_i \partial x_j} = (1 - \gamma_i) q_i'(x_i) q_j'(x_j) > 0$.

Further observe that both $SW(x_i, x_j)$ and $V_i(x_i, x_j)$ are supermodular. Thus, by the Topkis Theorem (Topkis (1998)), the optimal x_i is an increasing function of x_j.[28]

Next consider a hybrid problem of the following form:

$$H(\alpha, x_i, x_j) = (1 - \alpha)\, SW(x_i, x_j) + \alpha V_i(x_i, x_j) \tag{A4}$$

We have already shown that H is supermodular in (x_i, x_j). Observe now that $\frac{\partial^2 H_i}{\partial \alpha \partial x_i} = -\gamma_i q_i'(x_i) q_j(x_j) > 0$, implying that H is also supermodular in (α, x_i). Let (x_i^*, x_j^*) be the social optimum. Fixing $x_j = x_j^*$, we will now treat $H_i(\alpha, x_i, x_j^*)$ as a function with two variables, α and x_i. This is a supermodular function in α and x_i, as $\frac{\partial^2 H_i}{\partial \alpha \partial x_i} = -\gamma_i q_i'(x_i) q_j(x_j^*) > 0$.

By the Topkis theorem, $argmax_{x_i} V_i(x_i, x_j^*) > argmax_{x_i} SW_i(x_i, x_j^*) = SW_i(x_i^*, x_j^*)$. This follows from the fact that the optimal x_i is an increasing function of α, which implies that optimal x_i for $\alpha = 1$ is greater than the optimal x_i for $\alpha = 0$. Furthermore, because $V_i(x_i, x_j)$ is supermodular in x_i and x_j, the x_i maximizing V_i given x_j, rises with x_j.

We now define two sequences of strategies inductively: Let $x_2^1 = BR(x_1^*)$ denote player 2's best response to player 1's socially optimal strategy (with respect to V_1), where the superscript refers to the induction index. Likewise, let $x_1^1 = BR(x_2^*)$ define player 1's best response to player 2's socially optimal strategy. Applying a similar definition to the k'th iteration, let $x_2^k = BR\left(x_1^{k-1}\right)$, and $x_1^k = BR\left(x_2^k\right)$. Note that since V_i and V_j are supermodular with respect to x_i and x_j, it follows from the Topkis Theorem that $\{x_2^k\}$ and $\{x_2^k\}$ are increasing infinite sequences. Let $\hat{x}_i$ and $\hat{x}_j$ be the limits of these two sequences. Clearly $\hat{x}_i = BR\left(\hat{x}_j\right)$ and $\hat{x}_j = BR(\hat{x}_i)$. Hence, $\left(\hat{x}_i, \hat{x}_j\right)$ is a Nash equilibrium. Since the limits of these two sequences lie above x_i^* and x_j^*, the equilibrium involves excessive care.■

Proof of Proposition 4' (Excessive Care under Strict Liability – Variable Apportionment). The private value that player i maximizes is now given by:

$$V_i\left(x_i, x_j\right) = -C_i\left(x_i, x_j\right) = -q_i(x_i)\left(1 - q_j\left(x_j\right)\right) - \gamma_i(x_i, x_j)q_i(x_i)q_j\left(x_j\right) - c_i(x_i) \quad \text{(A5)}$$

Note that

$$\frac{\partial^2 V_i}{\partial x_i \partial x_j} = \left(1 - \gamma_i(x_i, x_j)\right)q_i'(x_i)q_j'\left(x_j\right) - \frac{\partial^2 \gamma_i}{\partial x_i \partial x_j} q_i(x_i)q_j\left(x_j\right) - \frac{\partial \gamma_i}{\partial x_i} q_i(x_i)q_j'\left(x_j\right) - \frac{\partial \gamma_i}{\partial x_j} q_i'(x_i)q_j\left(x_j\right).$$

Observe that condition (1) implies that $-\frac{\partial \gamma_i(x_i,x_j)}{\partial x_i} q_i(x_i)q_j'\left(x_j\right) - \frac{\partial \gamma_i(x_i,x_j)}{\partial x_j} q_i'(x_i)q_j\left(x_j\right) = 0$, and condition (2) implies that $\left(1 - \gamma_i(x_i, x_j)\right)q_i'(x_i)q_j'\left(x_j\right) > \frac{\partial^2 \gamma_i(x_i,x_j)}{\partial x_i \partial x_j} q_i(x_i)q_j\left(x_j\right)$. It thus follows that $\frac{\partial^2 V_i(x_i,x_j)}{\partial x_i \partial x_j} > 0$, which in turn implies that $V_i\left(x_i, x_j\right)$ and $SW(x_1, x_2)$ are supermodular (as established in Proposition 4). We next verify that $H_i(\alpha, x_i, x_j)$ is also supermodular with respect to α and x_i. Indeed $\frac{\partial^2 H_i}{\partial\alpha\partial x_i} = -\gamma_i q_i'(x_i) q_j(x_j *) - \gamma_i' q_i(x_i) q_j(x_j *) > 0$ (where the inequlity is due to the fact that $\frac{\partial \gamma_i(x_i, x_j)}{\partial x_i} < 0$). Thus, by the reasoning of Proposition 4, it follows that both players invest excessively in equilibrium. ■

Proof of Proposition 5 (Investment Incentives under Negligence): We prove the proposition by showing that if one player takes excessive care, the sequence of best responses unravels back to the care levels maximizing social welfare.

Denote by (x_1^0, x_2^0) the vector of maximal care levels. Let $x_2^1 = BR(x_1^0)$ denote player 2's socially optimal response to player 1's choice of x_1^0. Further, let $x_1^1 = BR(x_2^1)$ denote player 1's socially optimal response to x_2^1. Applying a similar definition to the k'th iteration, let $x_2^k = BR(x_1^{k-1})$, and $x_1^k = BR(x_2^k)$.

We have already shown that $SW(x_1, x_2)$ (given by (A3)) is supermodular. Therefore, by the Topkis Theorem, player i's socially optimal response increases with the level of care chosen by player j. Consider now the two infinite sequences $\{x_1^k\}$ and $\{x_2^k\}$. We shall next show by induction that these sequences are declining.

Note first that $x_2^0 > x_2^1$ and $x_1^0 > x_1^1$. Assume by induction that

$$x_2^1 > x_2^2 > \cdots > x_2^{k-1}; \text{ and that} \quad \text{(A6)}$$

$$x_1^1 > x_1^2 > \cdots > x_1^{k-1} > x_1^k \quad \text{(A7)}$$

By (A7), and by the fact that $x_2^k = BR(x_1^{k-1})$, it follows from the Topkis Theoreom that:

$$x_2^k > x_2^{k+1}. \tag{A8}$$

Similarly, by (A8) and the fact that $x_1^k = BR\left(x_2^k\right)$, it follows from the Topkis Theorem that:

$$x_1^k > x_1^{k+1} \tag{A9}$$

Hence the two sequences are declining and converging to a limit. Let x_1^{**} and x_2^{**} be the two limits of these sequences. By the definition of x_1^k and x_2^k as best responses we have

$$SW\left(x_1^k, x_2^k\right) \geq SW\left(x_1, x_2^k\right) \text{ for all } x_1. \tag{A10}$$

Furthermore,

$$SW\left(x_1^{k-1}, x_2^k\right) \geq SW\left(x_1^{k-1}, x_2\right) \text{ for all } x_2 \tag{A11}$$

Taking limits on both sides of equations (A10) and (A11) we have:

$$SW(x_1^{**}, x_2^{**}) \geq SW(x_1, x_2^{**}) \text{ for all } x_1. \tag{A12}$$

$$SW(x_1^{**}, x_2^{**}) \geq SW(x_1^{**}, x_2) \text{ for all } x_2 \tag{A13}$$

But this implies that $(x_1^{**}, x_2^{**}) = \operatorname{argmax} SW(x_1, x_2)$.

It remains to be shown that no equilibrium exists in which care is excessive. Suppose by way of contradiction that $(\hat{x}_1, \hat{x}_2)$ is an equilibrium, where $\hat{x}_1 > x_1^{**}$ or $\hat{x}_2 > x_2^{**}$. Without loss of generality, suppose that $\hat{x}_1 > x_1^{**}$. Given player 1's choice of $\hat{x}_1$, the negligence standard for player 2 will be set (by definition) at $BR(\hat{x}_1)$. Consequently, player 2 will not invest more than $BR(\hat{x}_1)$, since by choosing $x_2 = BR(\hat{x}_1)$ he could lower his cost of care without incurring any liability. But given player 2's choice of $x_2 \leq BR(\hat{x}_1)$, the standard of care applicable to player 1 will equal (at most) $BR\left(BR(\hat{x}_1)\right) < \hat{x}_1$, where the inequality follows from the fact that $\hat{x}_1 > x_1^{**}$ and $\{x_1^k\} \rightarrow x_1^{**}$. As player 1 too will have no incentive to invest more than required by the standard, he will choose a level of care lower than $\hat{x}_1$. This, in turn, implies that $\hat{x}_1$ cannot be an equilibrium strategy for player 1.■

Proof of Proposition 6. Let $s^* = (s_1^*, \dots, s_n^*)$ be the socially optimal strategy profile, and consider a Nash equilibrium $s = (s_1, \dots, s_n)$. We first establish that if $s_i^* = 0$ then $s_i = 0$. Since $s_i^* = 0$, if i chooses 0 then he is either not negligent under s, or if he is, then he is entitled to the defense (as by the optimality of s^*, he can show that s^* is superior to any profile in which $s_i = 1$). In both cases he is thus better off choosing 0.

We next show that if $s_i^* = 1$ then $s_i = 1$. Consider all players j such that $s_j^* = 1$ and $s_j = 0$. Denote the set of those players by E. The players in E are by definition negligent. This is because s^* satisfies $s_i^* \geq s_i$ for all i, and because all players in E satisfy $s_j^* > s_j$. Furthermore, none of the players in E are entitled to the defense, since the profile s^* yields greater social welfare than any profile in which each of these players chooses no care. Note that the probability that the negligence of one or more members in E will cause the harm is $q(s_{-E}^*) - q(s^*)$. Hence, the group's total expected liability is $q(s_{-E}^*) - q(s^*)$. But by the optimality of s^*, it must hold that $\sum_j c_j < q(s_{-E}^*) - q(s^*) = \sum_j \lambda_j(s_{-E}^*)$. As the group's total expected liability exceeds its aggregate cost of care, there must be at least one player in E for whom $c_j < \lambda_j(s_{-E}^*)$, which implies that player j is better off choosing care.

The foregoing thus establishes that if s is an equilibrium profile then $s = s^*$. To show that s^* is indeed an equilibrium, notice first that no player for whom $s_i^* = 0$ can be made better-off by deviating from 0 to 1 (as, given the defense, he bears no cost at all when choosing

0.) Furthermore, no player for whom $s_i^* = 1$ can be made better off by deviating to 0, as by the reasoning above, her cost in liability will exceed her cost of care. ■

Proof of Proposition 7a. Suppose otherwise, i.e., that $s_i^* = 0$ but there exists an equilibrium profile s in which $s_i = 1$. Observe that the choice of $s_i = 1$ may or may not reduce player i's ultimate liability. If it does not reduce her liability (e.g., because regardless of her choice of care she will be the only player causing harm), then choosing care produces no benefit for i.

Alternatively, if the choice of $s_i = 1$ reduces i's liability (either because, given care, i no longer causes the harm, or because the apportionment rule assigns lower liability to i), and there are other players who are liable, then the defense will apply and nullify those gains. Namely, there must be some player j who stands to benefit from invoking the defense, thereby shifting part of the liability burden to i. In that case, i will ultimately bear the same liability as if he chose $s_i = 0$ and caused the harm.

It follows that the only setting in which care may produce a gain for i (given the defense) is if doing so prevents i's causation of the harm, and harm has not been caused by any other injurer. Let $\pi(s^*, i)$ denote the probability that such a state of the world will eventuate, i.e.,

$$\pi(s^*, i) = Prob\left\{\omega | D_i(s^*_{-i}, 0, \omega) = 1 \wedge D_i(s^*_{-i}, 1, \omega) = 0 \wedge \prod_{i \neq j}\left(1 - D_j(s^*_{-i}, 1, \omega)\right) = 1\right\}.$$

Note that player i decreases social cost by moving from 0 to 1 by at least $\pi(s^*, i)$.[29] Furthermore, i is better off choosing care if and only if $\pi(s^*, i) > c_i$. Hence, i's contribution to the reduction of social cost by choosing care must also exceed c_i. But this contradicts the premise that $s_i^* = 0$.■

Proof of Proposition 7b. Let $s^* = (s_1^*, \dots, s_n^*)$ be the socially optimal action profile, and consider a Nash equilibrium $s = (s_1, \dots, s_n)$.

To establish that if $s_i^* = 0$ then $s_i = 0$, consider a player j such that $s_j^* = 0$ and $s_j = 1$. If harm is caused by at least one negligent injurer, then j will have gained nothing from choosing 1, as under the applicable rule she will have borne no liability regardless of her choice of care. Alternatively, if other players do not cause any harm, or if only non-negligent players cause harm, then the optimal strategy for j is to choose 0 by the proof of Proposition 7a.

It follows that if s is different from s^*, then it is only because there are players k for whom $s_k = 0$ even though $s_k^* = 1$. But if such players exist, then they must all be negligent. This is because for each player k it can be shown that for any profile in which $s_k = 0$, there exists a superior profile (namely s^*) in which all players choose at least as much care as in s, and in which $s_k = 1$. Hence, given the negligence of players k, they will be jointly liable for the entire harm. Since the cost of liability exceeds the aggregate cost of care for players k (by the optimality of s^*), choosing 1 must be optimal for at least one of them. It follows that at least one player carries an incentive to deviate from s. Therefore, s can be an equilibrium only if $s = s^*$.

To establish that s^* is indeed an equilibrium, notice first that by the reasoning above, no player choosing 0 can be made better-off by deviating to 1. Moreover, no player choosing

1 can be made better off by deviating to 0, as if she does, she will alone bear liability for the entire harm. As choosing 1 is socially optimal, it must be that her cost of liability in that case exceeds her cost of care. ■

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[1] The distinction between joint and alternative care was originally introduced by Landes and Posner (1980, 1987).

[2] Thus, for instance, if a drowning person calls for help, and multiple bystanders heed his call, a response by a single bystander may be enough to pull him back to safety. Once the first bystander reacts, there may be little value in other bystanders taking further action.

[3] Suppose, for instance, that a building may collapse due to either a flaw in the architect's plan, or a flaw in the contractor's method of construction. If either party's conduct is flawed, the other's precautionary efforts become futile, as either flaw alone is sufficient to trigger the harm. But if one party performs flawlessly, then the precaution of the other becomes critical, as it then exclusively controls the probability of harm.

[4] See, e.g., Cooter and Ulen (2016) ("[T]he injurer is liable under the Hand rule when further precaution is cost-justified."); Epstein and Sharkey (2016) ("[T]he skillful lawyer typically [proves the defendant's negligence] by pointing to some specific "untaken precaution" that, if taken, could have prevented the accident that actually occurred."); Fennell (2018) ("In the absence of a clear external standard for due care (such as a speed limit), attention tends to focus on "the untaken precaution"."); Stein (2017) ("any precaution that the actor can add to the precautions already taken becomes mandated when its cost falls below the value of the ensuing reduction in the harm's probability or magnitude.")

[5] Porat (2007) ("[C]ourts applying the Hand Formula need not accurately measure the expected harm, because it is sufficient that they determine whether the costs of the untaken precautions were higher or lower than the expected harm."); See similarly, Grady (1989), Ott and Schäfer (1997); Green (1997), Guttel (2007).

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[6] Harsanyi and Selten (1988) famously distinguished between the two motives affecting equilibrium selection. A broad experimental literature confirms both motives. See. e.g., Van Huyck et al. (1990); Cooper et al. (1992); Straub (1995); Devetag and Ortman (2006)). As expected, results largely depend on the stakes: namely, as the payoff associated with the payoff-dominant equilibrium rises, so does the tendency to converge to that equilibrium (Straub (1995); Battalio et al. (2001); Brandts and Cooper (2004)). Similarly, if the risk associated with a strategic mismatch increases, the tendency to converge to the risk-dominant equilibrium increases (Schmidt et al. (2003); Goeree and Holt (2005)). Results also depend on the degree of communication, which may mitigate coordination problems (Cooper et al. (1992); Blume and Ortmann (2007)) and on any information provided about the counterpart's prior choices (Duffy and Feltovich (2002)).

[7] Intuitively, when injurers may cause the harm with substantial probability even when taking precautions, the expected liability of each depends on the specifics of the apportionment rule. Hence, different rules may induce different incentives, thereby limiting the generality of the problem under strict liability. For further discussion, see Proposition 1.

[8] See http://www.atra.org/wp-content/uploads/2017/07/Record-07-06-17.pdf.

[9] See e.g., H.R.1215, 115th Cong. (2017) (proposing repeal of state joint and several liability laws in the area of medical malpractice).

[10] Ogden and Hylton (2016) examined a setting in which harm is inflicted not by multiple injurers, but rather by a single injurer and a victim who can invest in complement precautions. Their analysis too focuses on the role of apportionment rules (the choice between contributory and comparative negligence regimes).

[11] Alternative approaches to restoring optimal incentives suggested either that liability be allowed to diverge from harm (Miceli and Segerson, 1991; Cooter and Porat, 2007; Young et al., 2007; Marco et al., 2009;), or that multiple injurers be subject to unconventional principles of causation (Lando and Schweizer, 2017).

[12] The example assumes that when both factories take no-care, liability is divided equally between them. The first factory's incentive to refrain from care would only be reinforced if apportionment is sensitive to injurers' relative cost of care. In that case, the first factory's share might even exceed 5, given its lower cost of care. For a notable case by judge Posner suggesting that apportionment of liability should be based on a comparison of the "respective costs to the [parties] of avoiding the injury," see *Wassell v. Adams*, 865 F.2d 849 (7th Cir. 1989).

[13] Notice that excessive care will never emerge as a unique equilibrium under negligence. If one injurer acts efficiently by taking no-care, then the other will always be better off doing the same, as then the cost of care is avoided and no liability is incurred.

[14] This is tantamount to assuming that, for all s, and for any state ω in which harm occurs, $\sum_i D_i(s,\omega) > 0$. This assumption is without loss of generality, as the analysis could alternatively refer to a player's probability of causing harm as his conditional probability of causing it, given that nature was not the sole cause of harm. Attention is restricted to cases in which players cause the harm, in order to focus on the impact of tort law on behavior.

[15] Particularly, the premise that the probability of harm is zero when *all* choose care, also implies that for any individual player, choosing care precludes the possibility that he will cause harm. Hence, if all players but player j choose care, and harm occurs, then j must be the sole cause of the harm. Under strict liability, he must then bear full liability.

[16] Several papers in the law and economics literature have considered the interaction between the problem of multiple injurers and the problem of insolvency. The observation that insolvency increases the investment incentives of solvent injurers under strict liability is due to Kornhauser and Revesz (1992). Subsequent work focused on the relation between insolvency and the prospect of pre-trial settlement. Notably, Kornhauser and Revesz (1994) have shown that in the presence of insolvency, the likelihood of settlement depends on whether liability is non-joint or joint-and-several, on whether litigation outcomes are independent or correlated, and on the degree of insolvency. Spier (2002) has interestingly shown that in an opposite setting, where a single insolvent injurer is sued by multiple victims, settlement is likely when litigation outcomes are independent, but unlikely when they are correlated. For a literature review see Kornhauser and Revesz (2000).

[17] This definition mirrors the doctrinal "but for" test, under which an injurer's negligence is said to "cause" the harm if the harm would not have occurred had she acted reasonably. See Restatement (Third) of Torts: Liability for Physical and Emotional Harm, section 26: “Tortious conduct must be a factual cause of harm for liability to be imposed”. Accordingly, in negligence claims, plaintiff must establish that defendant’s “tortious conduct”, namely his negligent behavior, was the cause of the harm. See Illustration 2 (“While driving 57 miles per hour on a road with a 50-miles-per-hour speed limit, Ken ran into Melanie, a pedestrian.

Ken is not subject to liability for negligence in speeding unless he would not have hit Melanie or would have caused her less harm if he had been driving 50 miles per hour.")

[18] An alternative approach to contending with the excessive care problem might be to impose liability that is lower than the harm. Such an approach, however, would carry three significant drawbacks: First, it would require precise tuning of the level of liability to the particular technology of care in any given case, so as to ensure that players do not shift to an equilibrium of under-investment. Second, even if such fine-tuning is possible, it would create an under-investment problem when excessive care and efficient care are both equilibria under the current regime (as the efficient equilibrium would then inevitably turn into an equilibrium of under-investment). Third, such a solution would depart from a basic principle of tort law, under which victims are compensated in full when entitled.

[19] Recall that the argument is inapplicable under the continuous model, as excessive care does not emerge under negligence in the continuous case.

[20] Further note that the first prong of the rule is largely congruent with existing doctrinal principles. As mentioned, the rule of apportionment under the Restatement provides that liability ought to be shared according to "*relative responsibility*" (see Restatement (Third) of Torts: Apportionment of Liability, section 8). While the precise meaning of that term is not entirely defined, the general notion that negligent injurers should bear the lion's share of the harm, seems to lie within the bounds of the rule's reasonable interpretation. Conversely, the second prong of the rule, encompassing the excessive-care defense, is a novel element of the proposed rule.

[21] Restatement (Second) of Contracts, section 192.

[22] Restatement (Third) of Torts: Apportionment of Liability, section 8.

[23] Recall that filters are of no value unless installed by both; hence their social cost is 90. Their social benefit is 30 as they are beneficial only in the event that neither factory pollutes—an outcome occurring with a 25% chance.

[24] The expected cost of 90 is given by the cost of care, plus a 25% chance of bearing liability for the entire harm, plus a 25% chance of bearing liability for half of the harm (45 + 25%×120 + 25%×60 = 90).

[25] The expected cost of 65 is given by the cost of care, plus a 50% chance of bearing liability for a third of the harm (45 + 50%×40 = 65). The expected cost of 100 is given by the 50% chance of bearing liability alone, plus a 50% chance of bearing liability for 2/3 of the harm (50%×120 + 50%×80 = 100).

[26] The expected cost of 57 is given by the cost of care, plus a 50% chance of bearing liability for a fifth of the harm (45 + 50%×24 = 57). The expected cost of 108 is given by the 50% chance of bearing liability alone, plus a 50% chance of bearing liability for 4/5 of the harm (50%×120 + 50%×96 = 108).

[27] The Federalist No. 15 (Alexander Hamilton).

[28] This property is also referred to as "strategic complementarity". See, e.g., Bulow, Geanakoplos and Klemperer (1985).

[29] Note that the overall effect on social cost may also include an additional element, emanating from *i*'s indirect effect on other players' causation.

References

Aumann Robert J. 1990. “Nash Equilibria are not Self-Enforcing,” in J.J. Gabszewicz, J.F. Richard, L. Wolsey, eds., *Economic Decision Making: Games, Econometrics and Optimisation*. Amsterdam, Netherlands: North-Holland.

Battalio, R., L. Samuelson and J. Van Huyck. 2001. “Optimization Incentives and Coordination Failure in Laboratory Stag-hunt Games,” *Econometrica* 69:749.

Blume, A. and A. Ortmann. 2007. “The Effects of Costless Pre-Play Communication: Experimental Evidence from Games with Pareto-Ranked Equilibria,” *Journal of Economic Theory* 132:274.

Brandts, J. and D. J. Cooper. 2004. “A Change Would Do You Good… An Experimental Study on How to Overcome Coordination Failure in Organizations,” *American Economic Review* 96:669.

Brown John P. 1998. Learned Hand Rule, in Peter Newman (ed) *The New Palgrave Dictionary of Economics and The Law* 2:514.

Bulow, J.I., J.D. Geanakoplos and P.D. Klemperer. 1985. "Multimarket Oligopoly: Strategic Substitutes and Complements," *Journal of Political Economy* 93:488.

Cooper, R., D.V. DeJong, R. Forsythe and T.W. Ross. 1992. "Communication in Coordination Games," *Quarterly Journal of Economics* 107:739.

Cooter, R. and A. Porat. 2007. "Total Liability for Excessive Harm," *Journal of Legal Studies* 36:63.

Cooter, R. and T. Ulen. 2016. *Law and Economics*. Boston, Mass.: Pearson.

Devetag, G. and A. Ortmann. 2006. "When and Why: A Critical Survey on Coordination Failure in the Laboratory," *Experimental Economics* 10:331.

Dillbary, J. Shahar. 2013. "Tortfest," *University of Chicago Law Review* 80:953.

Duffy, J. and N. Feltovich. 2002. "Do Actions Speak Louder Than Words? Observation vs. Cheap Talk as Coordination Devices," *Games and Economic Behavior* 39:1.

Epstein, R.A. and C.M. Sharkey. 2016. *Cases and Materials on Torts*. New York, NY: Wolters Kluwer.

Feess, E. and U. Hege. 1998. "Efficient Liability Rules for Multi-Party Accidents with Moral Hazard," *Journal of Institutional and Theoretical Economics* 154:422.

Fennell, Lee Anne. 2018. "Accidents and Aggregates," *William and Mary Law Review* 59:23.

Ferey, S. and P. Dehez. 2016. "Multiple Causation, Apportionment, and the Shapley Value," *Journal of Legal Studies* 45:143.

Goeree, J.K. and C.A. Holt. 2005. "An Experimental Study of Costly Coordination," *Games and Economic Behavior* 51:349.

Grady, Mark. 1988. "Common Law Control of Strategic Behavior: Railroad Sparks and the Farmer," *Journal of Legal Stud* 17:15.

------. 1989. "Untaken Precautions," *Journal of Legal Studies* 18:139.

Green, Michael D. 1997. "Negligence = Economic Efficiency: Doubts >," *Texas Law Review* 75:1605.

Guttel, Ehud. 2007. "The (Hidden) Risk of Opportunistic Precautions," *Virginia Law Review* 93:1389.

Guttel, E. and S. Leshem. 2014. "The Uneasy Case of Multiple Injurers' Liability," *Theoretical Inquiries in Law* 15:261.

Halac, M., I. Kremer and E. Winter. 2020. "Raising Capital from Heterogeneous Investors," *American Economic Review* 110:889.

Harel, A. and A. Jacob. 2002. "An Economic Rationale for the Legal Treatment of Omissions in Tort Law: The Principle of Salience," *Theoretical Inquiries in Law* 3:413.

Harsanyi, J. and R. Selten. 1988. *A General Theory of Equilibrium Selection in Games*. Cambridge, Mass.: MIT Press.

Jacob, Assaf. 2009. "Dilution of Liability and Multiple Tortfeasors in the Context of Liability for Unrequested Precautions," *Michigan Law Review First Impressions* 108:12.

Kaye, D. and M. Aickin. 1984. "A Comment on Causal Apportionment," *Journal of Legal Studies* 13:191.

Keeton, W. P., D. B. Dobbs, R.E. Keeton, and D.G. Owen. 1984. *Prosser and Keeton on the Law of Torts*. 5th ed. St. Paul, MN: West.

Kornhauser, L.A., and R.L. Revesz. 1989. "Sharing Damages among Multiple Tortfeasors," *Yale Law Journal* 98:831.

------. 1990. "Apportioning Damages among Potentially Insolvent Actors," *Journal of Legal Studies* 19: 617.

------. 1994. "Multidefendant Settlements under Joint and Several Liability: The Problem of Insolvency." *Journal of Legal Studies* 23:517.

------. 2000. "Joint Tortfeasors," in B. Bouckaert and G. de Geest, eds., *Encyclopedia of Law and Economics*. 2:625. Cheltenham, UK and Ghent, Belgium: Edward Elgar Publishers.

Landes, W. and R.A. Posner. 1980. "Joint and Multiple Tortfeasors: An Economic Analysis," *Journal of Legal Studies* 9:517.

------. 1987. *The Economic Structure of Tort Law*. Cambridge, Mass.: Harvard Univ. Press.

Lando, H. and U. Schweizer. 2017. "Causality and Incentives with Multiple Tortfeasors," *Available at SSRN: https://ssrn.com/abstract=2985532*.

Leshem, Shmuel. 2017. "Allocation of Liability: On the Efficiency of Composite Sharing Rules," *Journal of Institutional and Theoretical Economics* 173:25.

Levmore, Saul. 1986. "Waiting for Rescue: An Essay on the Evolution and Incentive Structure of the Law of Affirmative Obligations," *Virginia Law Review* 79:879.

Marco, A.C., A.S. Vanwoerden, and R. M. Woodward. 2009. "The Problem of Shared Social Cost," *Review of Law and Economics* 5:137.

Miceli, T.J. and K. Segerson. 1991. "Joint Liability in Torts: Marginal and Infra-Marginal Efficiency," *International Review of Law and Economics* 11:235.

Monderer, D. and L. Shapley. 1996. "Potential Games," *Games and Economic Behavior* 14: 124.

Ogden, B. and K.N. Hylton. 2016. "Incentives to Take Care Under Contributory and Comparative Fault," *Available at SSRN: http://dx.doi.org/10.2139/ssrn.2564260.*

Ott, C. and H. Schäfer. 1997. "Negligence as Untaken Precaution, Limited Information and Efficient Standard Formation in the Civil Liability System," *International Review of Law and Economics* 17:15.

Porat, Ariel. 2007. "Offsetting Risks," *Michigan Law Review* 106:243.

Rizzo, M.J., and F.S. Arnold. 1980. "Causal Apportionment in the Law of Torts: An Economic Theory," *Columbia Law Review* 80:1399.

------. 1986. "Causal Apportionment: Reply to the Critics," *Journal of Legal Studies* 15:219.

Schmidt, D., R. Shupp, J.M. Walker, and E. Ostrom. 2003. "Playing Safe in Coordination Games: The Roles of Risk Dominance, Payoff Dominance, and History of Play," *Games and Economic Behavior* 42:281.

Schweizer, Urs. 2016. “Efficient Incentives from Obligation Law and the Compensation Principle,” *International Review of Law and Economics* 45:54.

Shavell, Steven. 1987. *Economic Analysis of Accident Law*. Cambridge, Mass.: Harvard Univ. Press.

Spier, Kathryn. 2002. “Settlement with multiple plaintiffs: The role of insolvency,” *Journal of Law, Economics, and Organization* 18:295.

Stein, Alex. 2017. “The Domain of Torts,” *Columbia Law Review* 117:535.

Straub, Paul G. 1995. “Risk Dominance and Coordination Failures in Static Games,” *Quarterly Review of Economics and Finance* 35:339.

Topkis, M. Donald. 1998. *Supermodularity and Complementarity*. Princeton, NJ: Princeton Univ. Press.

Tuch, Andrew F. 2010. “Multiple Gatekeepers,” *Virginia Law Review* 96:1583.

Van Huyck, J.B., R.C. Battalio and R.O. Beil. 1990. “Tacit Coordination Games, Strategic Uncertainty, and Coordination Failure,” *American Economic Review* 80:234.

Winter, Eyal. 2004. “Incentives and Discrimination,” *American Economic Review* 94:764.

Young, R., M. Faure, and P. Fenn. 2007. “Multiple Tortfeasors: An Economic Analysis,” *Review of Law and Economics* 3:111.