The Uneasy Case of Multiple Injurers' Liability

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When harm is caused by multiple injurers, damages are allocated among the responsible injurers in proportion to their relative responsibility for harm. This Article shows that a proportional allocation of liability between strictly-liable injurers distorts incentives to take precautions. The effects of this distortion depend on the nature of the injurers' precautions. If precautions are complements, injurers compete for lower liability shares, which results in excessive care-taking. If precautions are substitutes, injurers are afflicted by moral hazard, which gives rise to insufficient care-taking. By illuminating injurers' strategic incentives, this Article highlights a tension between equity and efficiency under a proportional allocation of liability.

Introduction

Harm caused by multiple injurers is widespread. Prominent examples include a consortium of plants whose combined emissions result in pollution; manufacturers of components that render an end-product unsafe and thus potentially harmful to consumers; and drivers who collide and injure a bystander.

Two alternative tort regimes govern the liabilities of multiple injurers. Although different in several important respects, both regimes allocate responsibility for victims' harm among liable injurers similarly. Under a "several" liability rule, a victim can recover from each injurer damages that reflect that injurer's relative share of the total harm. Accordingly, courts determine the individual liability of each injurer as part of the victim's lawsuit itself. Under the alternative "joint and several" liability rule, a victim can collect

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her entire damages from any of the responsible injurers. However, injurers who end up paying more than their relative share may seek "contribution" from injurers who pay less than their relative share.[1] Thus, once all contribution suits are settled, each injurer's payment reflects his corresponding share of the total harm, much like the allocation of liability under a several liability rule.[2]

The allocation of liability among multiple injurers (under either a "several" or "joint" liability rule) has conventionally been predicated on a comparison of injurers' risk-creating conduct. To make this comparison, courts examine the inherent riskiness of each injurer's activity — as reflected in the injurer's choice of care relative to the care level of other injurers — and impose a greater share of liability on injurers whose conduct involves greater risk.[3] This comparison, as courts and commentators have reasoned, is justified on both fairness and efficiency grounds.[4] From a fairness perspective, the riskiness of an injurer's conduct manifests his degree of indifference towards victims' interests.[5] From an efficiency perspective, such an allocation of liability supposedly aligns

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1 Although originally developed in the context of negligence claims, contribution "is now allowed in favor of or against tortfeasors who are not negligent at all but only strictly liable." Dan B. Dobbs, Paul T. Hayden & Ellen M. Bublick, The Law of Torts § 489 (2d ed. 2012). Apportionment among strictly-liable defendants is thus the result under both several-only and joint-and-several liability regimes.

2 *See id.* § 487 (providing an overview of several-liability and joint-and-several-liability regimes and their application in the various states).

3 Assignment of responsibility among liable parties, according to the Restatement (Third) of Torts: Apportionment of Liability § 8 cmt. a (2000), should be predicated on "the nature of the person's risk creating conduct" and "the strength of the causal connection between the person's risk-creating conduct and the harm." Because parties' precautions determine both the riskiness of their activities as well as their causal contribution, apportionment of liability often centers on comparison of the parties' levels of care. *See, e.g.*, Dobbs, Hayden & Bublick, *supra* note 1 (in a car accident involving a bystander and two drivers, apportionment of liability should be based on the degree of each driver's lack of care).

4 *See, e.g.*, Gerald W. Boston, *Toxic Apportionment: A Causation and Risk Contribution Model*, 25 Envtl. L. 549 (1995) (arguing that apportionment of liability on the basis of parties' relative carelessness is justified by both fairness and efficiency considerations).

5 *See, e.g.*, Gem Developers v. Hallcraft Homes of San Diego, Inc., 213 Cal. Rptr. 3d 419, 426 (Cal. Ct. App. 1989) (explaining that apportionment of liability among strictly-liable defendants is necessary to "avoid the unfairness . . . of holding one defendant liable for the plaintiff's entire loss while allowing another responsible defendant to escape scot free").

injurers' individual interests with the socially optimal allocation by holding each injurer liable for his respective contribution to the harm.[6]

This Article shows that despite its intuitive appeal, a proportional allocation of liability prompts injurers to act strategically in a way that reduces social welfare. In particular, potential injurers, subject to strict liability, might engage in either free-riding or rent-seeking, depending on the nature of their precautions. Scaling liability in proportion to injurers' relative carelessness might therefore compromise efficiency. In particular, to provide efficient incentives, liability should be tilted (relative to a proportional allocation) in favor of one injurer — either the careless or the careful — depending on whether injurers' precautions are complements or substitutes. Our Article therefore highlights a tension between equity and efficiency inherent in a proportional allocation of responsibility among strictly liable parties.

Injurers' incentives to act strategically arise from the relationship between each injurer's dual benefit from taking care: reduction of harm and shifting of liability. To see this, suppose that two injurers jointly cause harm, and consider the effect one injurer's increase in his level of care has on the other injurer's expected liability. On the one hand, by raising his level of care, an injurer reduces the probability of harm. This reduction in risk creates a *positive externality* for the other injurer, who now faces a lower expected liability. On the other hand, under a proportional allocation of liability, an injurer's increased care reduces his share of liability. Because this smaller share of liability entails a greater share for the other injurer, an increase in one injurer's level of care creates a *negative externality* for the other injurer. The different externalities caused by an increase in one injurer's care could in turn affect the other injurer's liability.

The overall effect of an increase in one injurer's level of care on the other injurer's incentives to take care depends, as we show in this Article, on the relationship between the injurers' precautions. If the injurers' precautions are substitutes (in a sense we define more precisely below), the reduction in liability due to an injurer's care is lower than the corresponding decrease in expected harm (so the positive externality outweighs the negative one). The injurers may thus attempt to free ride on each other's efforts by taking insufficient care. In contrast, if the injurers' precautions are complements, the reduction in liability due to an injurer's care is greater than the corresponding decrease in expected harm (so the negative externality outweighs the positive one).

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6 *See, e.g.*, United States v. Reliable Transfer Co., 421 U.S. 397, 405 n.11 (1975) ("A rule that divides damages by degree of fault would seem better designed to induce care . . . because it imposes the strongest deterrent upon the wrongful behavior that is most likely to harm others.").

Injurers will therefore compete over a lower liability share, and accordingly take excessive care. Most important, whether injurers attempt to free ride or to engage in rent-seeking, a proportional allocation of liability gives rise to strategic behavior, which often reduces social welfare.[7]

Previous scholarship on the incentives transmitted by allocation rules under strict liability has noted that such rules might cause a "dilution of liability" and thereby erode injurers' incentives to take precaution. Dilution of liability occurs when injurers precautions are perfect substitutes and therefore one injurer's care confers a positive externality on the other injurer (who is exempt from liability by the first injurer's care).[8] This literature, however, has largely focused on cases in which each injurer can entirely prevent harm on his own. This assumption confines the analysis to a special case in which taking care affects only the probability of harm but not the allocation of liability once harm occurs (because if any injurer takes care, harm is avoided). This Article considers the more general case in which injurers' precautions reduce, but do not eliminate, the risk of harm. It shows that if injurers' precautions are substitutes, a similar problem of "dilution of liability" may arise in this more general case as well. Moreover, we show that dilution of liability is not the only reason for injurers to take too little care. Coordination problems among injurers might similarly give rise to socially inefficient levels of care.

In an influential paper, Lewis Kornhauser and Richard Revesz emphasized the risk of inefficient care when expected harm increases rapidly with injurers' activity levels (i.e., where harm is a convex function of injurers' activity levels). They showed that in this case a proportional allocation of liability induces injurers to over-engage in their activities, thereby exposing victims to excessive risk.[9] The core of Kornhauser and Revesz's insight hinges on the failure of

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7 As others have shown in the context of surplus sharing, the distortionary effects of a proportional allocation depend more generally on the properties of the production function (whether it exhibits increasing or decreasing returns to scale). The problem of surplus sharing is analogous to that of harm sharing in that both problems involve the allocation of a joint output among multiple contributing agents. *See* Dwight Israelsen, *Collectives, Communes, and Incentives*, 4 J. Comp. Econ. 99 (1980); Amartya Sen, *Labour Allocation in a Cooperative Enterprise*, 33 Rev. Econ. Stud. 361 (1966).

8 *See* Steven Shavell, Economic Analysis of Accident Law 166 (1987); Alon Harel & Assaf Jacob, *An Economic Rationale for the Legal Treatment of Omissions in Tort Law: The Principle of Salience*, 3 Theoretical Inquiries L. 413 (2002); Saul Levmore, *Waiting for Rescue: An Essay on the Evolution and Incentive Structure of the Law of Affirmative Obligations*, 72 Va. L. Rev. 879 (1986).

9 Lewis Kornhauser & Richard Revesz, *Sharing Damages Among Multiple Tortfeasors*, 98 Yale L.J. 831 (1989); *see also* Lewis Kornhauser & Richard

a proportional-allocation rule to account for the individual contribution of each injurer's activity to the entire harm. Here we replicate Kornhauser and Revesz's result in the case of substitute precautions involving a different harm function. More important, we show that in the case of complementary precautions, strict liability may induce injurers to take excessive precaution. Accordingly, from a social perspective, strict liability may result in too much, rather than too little, care.

Finally, the distinction between substitute and complementary precautions has been discussed by others, but with little attention to the implications of this distinction for injurers' incentives to take optimal care under a strict-liability regime. William M. Landes and Richard A. Posner distinguished between "joint care" cases, in which it is optimal for both potential injurers to take care (complementary precautions), and "alternative care" cases, in which it is efficient for only one potential injurer to take care (substitute precautions).[10] They harnessed this distinction to explicate the common law doctrines of no-contribution and indemnity. Carvell and others adopted Landes and Posner's distinction between complementary and substitute precautions (i.e., "joint" versus "alternative") to identify the effects of the movement from joint-and-several liability to several-only liability on injurers' incentives to take care.[11] Unlike the present Article, both Landes and Posner's and Carvell et al.'s papers focus on a negligence regime. As a result, both papers do not fully consider the incentive effects of a proportional-allocation rule that is based on injurers' relative carelessness, as we do here.

The Article is organized as follows. Part I shows that the distortionary effects of a proportional allocation of liability on injurers' incentives to take care depend on the interplay between injurers' precautions. Part II then considers the implications of the analysis in Part I. In particular, it discusses the tension between equity and efficiency under a proportional allocation of strict liability, characterizes the nature of the strategic interaction between injurers under different precaution technologies, and extends the analysis to the case in which injurers take actions in sequence. An Appendix, which generalizes the results in Part I, follows the Conclusion.

Revesz, *Evaluating the Effects of Alternative Superfund Liability Rules*, *in* Analyzing Superfund: Economics, Science, and Law 115 (Richard L. Revesz & R. Stewart eds., 1995).

10 William M. Landes & Richard A. Posner, *Joint and Multiple Tortfeasors — An Economic Analysis*, 9 J. Legal Stud. 517 (1980).

11 Daniel Carvell et al., *Accidental Death and the Rule of Joint and Several Liability*, 43 Rand J. Econ. 51 (2012).

I. Multiple Injurers and Optimal Care

A. Allocation of Liability Under Negligence Versus Strict Liability

Before turning to investigating the consequences of allocating liability among strictly liable injurers, it is worth examining the implications of such an allocation rule under negligence. Injurers subject to negligence can avoid liability by taking sufficient care. As others have shown, as long as courts set the standard of care optimally, injurers' incentives to take precaution are aligned with social efficiency, independently of the rules for allocating liability.[12] The intuition for this result is that under any allocation rule, at least some injurers are better off complying with the negligence standard. Because these injurers avoid liability by taking due care, the remaining injurers must pay the entire damages if harm occurs and therefore minimize their costs by taking optimal care as well.[13] Thus, allocation of liability under negligence has no actual bearing on injurers' incentives to take optimal care.[14]

Under strict liability, in contrast, injurers must compensate victims for their harm irrespective of their level of care. Taking optimal care thus does not carry the same benefit (avoidance of liability) that it provides under negligence. Instead, as we noted earlier, injurers' choices of care affect the probability of harm, as well as each injurer's expected share of liability. It is the interaction between these two effects that makes rules for allocating liability more important under strict liability than under negligence. As shown in this Article, a proportional allocation of damages under strict liability may induce injurers to take either too little or too much care, depending on the nature of

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12 *See, e.g.*, Shavell, *supra* note 8, at 165-66.

13 To illustrate, suppose that two injurers, A and B, can prevent a harm of 100 by taking precaution, each at a cost of 20. Further suppose that if harm occurs, liability is allocated disproportionately, such that A pays 90% of the victim's harm and B pays only 10%. Under negligence, A is better off complying with the negligence standard (investing 20 in precautions) than paying damages (90). Because A takes care, B is also better off complying with the standard than paying the entire damages (20 < 100). A similar analysis — in which it is in the interest of one injurer, and therefore also of the other, to take care — applies to any allocation rule.

14 *But see* Carvell et al., *supra* note 11 (setting up a model in which each injurer's negligence liability is a decreasing function of his level of care, and showing that because the optimal level of care is determined ex post, the allocation of liability affects injurers' incentives to take socially efficient care). However, the allocation of liability in Carvell et al.'s paper only arises when both injurers are found negligent.

their precautions. Thus, in contrast to negligence, the allocation of liability among strictly liable injurers has a significant effect on injurers' behavior.

Our analysis employs a numerical example involving two manufacturers that produce the components of a consumer end-product (the analysis is generalized in the Appendix), where the manufacturers are strictly liable for any harm consumers suffer from defective components.[15] Accordingly, the level of the manufacturers' care has no consequence for their joint liability.[16] However, in allocating damages between the manufacturers, a court must examine each manufacturer's relative contribution to the harm caused. Products liability (for harm caused by defective components) thus provides a common example of a regime involving strict liability and a proportional allocation of damages. Although we focus on products liability, our analysis applies to other cases — such as pollution and car accidents involving multiple parties — in which injurers are strictly liable for victims' harm, and their liability is allocated in proportion to the relative riskiness of their conduct.

B. Substitute Precautions

Suppose that a certain consumer product consists of two components, each produced by a different manufacturer (manufacturers A and B). Each component's quality is contingent on its manufacturer's level of care. If a manufacturer takes no care, the probability of a defective component is ⅔. If a manufacturer takes care, this probability is reduced to ⅓.[17] Finally, suppose that if harm occurs, the consumers' loss is 90.[18]

In this Section, we consider the case in which the manufacturers' precautions are *substitutes*.[19] This implies that consumers suffer harm if, and only if, both manufacturers' components are defective. The following table summarizes the probability of harm and expected harm as functions of each manufacturer's level of care:

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15 *See* Restatement (Third) of Torts: Products Liability § 5 (2012) (manufacturers of defective components are strictly liable for harm caused by the end product).

16 For further discussion, see *infra* note 25.

17 We (implicitly) assume that the quality of one manufacturer's component does not affect the other manufacturer's cost of reducing the probability that his component is defective.

18 We assume that the manufacturers cannot, or it would be too costly for them, to enter a contract which requires each of them to take the socially-optimal level of care.

19 We use the term "substitutes" in a *narrow* sense (which we define below), rather than to capture generally negative cross-effects between the manufacturers' precautions.

Table 1: Probability of Harm and Expected Harm (Substitute Precautions)

Manufacturers' Care Levels	Prob. of Harm	Expected Harm
Both take no care	$\frac{4}{9}$ ($\frac{2}{3} \times \frac{2}{3}$)	40
One takes care, one does not	$\frac{2}{9}$ ($\frac{1}{3} \times \frac{2}{3}$)	20
Both take care	$\frac{1}{9}$ ($\frac{1}{3} \times \frac{1}{3}$)	10

First, consider the case in which both manufacturers take no care. Because the probability that each manufacturer will produce a defective component is $\frac{2}{3}$, the overall probability that the end-product will cause harm is $\frac{4}{9}$ ($\frac{2}{3} \times \frac{2}{3}$). Next, suppose that one manufacturer takes care, while the other does not. Then, there is a probability of $\frac{1}{3}$ that one component will be defective and a probability of $\frac{2}{3}$ that the other component will be defective. The probability that the end-product will cause harm is accordingly $\frac{2}{9}$ ($\frac{1}{3} \times \frac{2}{3}$). Finally, when both manufacturers take care, there is a probability of $\frac{1}{3}$ that each manufacturer will produce a defective component. The probability that the end-product will cause harm is therefore $\frac{1}{9}$ ($\frac{1}{3} \times \frac{1}{3}$).

As Table 1 shows, because the end-product causes harm only when both components are defective, the benefit from one manufacturer's care is greater when the other manufacturer takes no care. If one manufacturer is careless, the other manufacturer saves 20 in expected harm by being careful (because he thereby reduces the expected harm from 40 to 20). If one manufacturer is careful, however, the other manufacturer saves only 10 in expected harm by being careful (because he thereby reduces the expected harm from 20 to 10). This result stems from the substitutability between the manufacturers' precautions. When one manufacturer is careless, the other manufacturer's choice of care becomes more pivotal. Because one manufacturer takes no care, the other manufacture's care significantly reduces the expected harm. In contrast, when one manufacturer is careful, the other manufacturer's care becomes less pivotal. Because one manufacturer's care already significantly reduces the probability of harm, the other manufacturer's care is relatively less effective in reducing the expected harm. The essential feature of substitute precautions that affects injurers' incentives under a proportional allocation of liability, however, is that a decrease of 50% of each component's probability of being defective (from $\frac{2}{3}$ to $\frac{1}{3}$) reduces expected harm by *more* than 50% (from 40 to 10). This implies that the harm-reducing technology exhibits *increasing returns to scale*.

Against this background, consider now each manufacturer's choice of care under a strict liability regime in which manufacturers must compensate consumers for the entire harm caused. Because the manufacturers are jointly liable, they share damages according to their *relative responsibility* for the harm.

We first assume that each manufacturer's cost of care is 16. It is straightforward to show that, from a social perspective, it is desirable that one manufacturer should take care and the other not. This is because, when one manufacturer takes care at a cost of 16, the expected harm is reduced by 20 (from 40 to 20). Given that one manufacturer is careful, however, the other manufacturer's care reduces the expected harm by less than 16 (from 20 to 10). Accordingly, to maximize social welfare, one and only one manufacturer should take care.

Although efficiency requires that one manufacturer should take care, each manufacturer, acting strategically, would prefer to take no care. The matrix in Table 2 presents the manufacturers' overall costs, composed of their expected liability and their costs of care, as functions of their care levels. Because the manufacturers' payoffs are symmetric, it suffices to consider the payoff of a single manufacturer (manufacturer A) under the four possible combinations of the manufacturers' choice of care:

Table 2: Manufacturers' Payments (Substitute Precautions; Cost of Care Equals 16)

		Manufacturer B	
		Care	No Care
Manufacturer A	Care	21	22⅔
	No Care	13⅓	20

Consider first the two cases in which the manufacturers choose the same level of care. In these cases, the risk involved in each manufacturer's behavior is identical. Under a proportional liability rule, the manufacturers therefore share equally in the expected harm. Consequently, if both manufacturers are careless, each faces an expected liability of 20 (½ × 40). If both manufacturers are careful, each faces an expected liability of 5 (½ × 10) and spends 16 on care for a total of 21 (5 + 16).

Next, consider the two cases in which the manufacturers choose different levels of care. If one manufacturer takes care, while the other does not, the careless manufacturer's product is defective with a probability of ⅔ and the careful manufacture's product is defective with a probability of ⅓. Accordingly, under a proportional liability rule, the careless manufacturer's expected liability is 13⅓ (⅔ × 20), while the careful manufacturer's expected liability is 6⅔ (⅓ × 20). The careless manufacturer's total costs are thus 13⅓ (because it bears no costs of care), whereas the careful manufacturer's total costs are 22⅔ (6⅔ +16).

As the matrix in Table 2 shows, each manufacturer's best response to *any* choice of care by the other manufacturer is to take no care. Although taking no care is a dominant strategy for each manufacturer, the resulting dominant-strategy equilibrium fails to minimize the manufacturers' aggregate costs. When neither manufacturer takes care, the manufacturers' joint costs are 40. If, instead, one manufacturer takes care while the other does not, the manufacturers' aggregate costs are only 36 (22⅔ + 13⅓). Because the manufacturers are liable for the entire harm, the manufacturers' loss of 4 also represents the social loss from their inefficient behavior.

We now turn to the more general case, in which each manufacturer's cost of care is c. Recall that the additional benefit from each manufacturer's care decreases with the amount of care (as shown in Table 1). Thus, if one manufacturer takes care, the expected harm is reduced by 20, whereas if the other manufacturer also takes care, the further reduction in expected harm is only 10. Accordingly, when c is lower than 10, efficiency requires that both manufacturers take care. If c is greater than 10, but less than 20, only one manufacturer should take care. And if c is greater than 20, no manufacturer should take care.[20] Under a proportional allocation rule, however, the manufacturers have insufficient incentives to take care. To see this, consider manufacturer A's payment as a function of each manufacturer's level of care[21]:

Table 3: Manufacturers' Payments (Substitute Precautions; General Case)

		Manufacturer B	
		Care	No Care
Manufacturer A	Care	$5 + c$	$6⅔ + c$
	No Care	13⅓	20

As the matrix in Table 3 shows, each manufacture's dominant strategy is to take care for low values of c (c less than 8⅓). For such values of c, each manufacturer minimizes his cost of care and expected liability by taking care,

20 To keep the analysis simple, we assume that c does not take threshold values. In the Appendix, we adopt a tie-breaking rule to resolve ties.

21 In the Appendix, we generalize the results to the case in which the probability of harm, as a function of each manufacturer's level of care, can take any value between 0 and 1.

irrespective of the other manufacturer's choice of care (because, for c less than 8⅓, 5 + c is less than 13⅓ and 6⅔ + c is less than 20). Similarly, each manufacturer's dominant strategy is to take no care for high values of c (c greater than 13⅓). For such values of c, each manufacturer minimizes his aggregate costs by taking no care, irrespective of the other manufacturer's choice of care (because, for c greater than 13⅓, 5 + c is greater than 13⅓ and 6⅔ + c is greater than 20). Finally, for intermediate values of c (c between 8⅓ and 13⅓), each manufacturer minimizes his aggregate costs by choosing a level of care opposite to the other manufacturer's level of care (because, for c between 8⅓ and 13⅓, 5 + c is greater than 13⅓, but 6⅔ + c is less than 20).

It should now be clear that the manufacturers have insufficient incentives to take care. If c is between 8⅓ and 10, efficiency requires that both manufacturers should take care, but each manufacturer would prefer to take no care if the other manufacturer is careful. If c is between 13⅓ and 20, it is efficient for one manufacturer to take care, but each manufacturer would prefer to take no care, irrespective of the other manufacturer's choice of care. Finally, if c is between 10 and 13⅓, it is again efficient for one manufacturer to take care, but the manufacturers must coordinate on which of them should take care. In the absence of coordination, the manufacturers are likely to randomize (in equilibrium) between taking care and taking no care.[22] Apportioning damages between the manufacturers according to the relative safety of their components thus results in a *dilution of liability*.

This example reveals the distortionary effect of a proportional allocation rule on manufacturers' incentives to prevent harm. This distortion results from the difference between the actual contribution of each manufacturer's care to the reduction in expected harm, on the one hand, and each manufacturer's corresponding liability gain from taking care, on the other. To understand why a proportional allocation rule dilutes manufacturers' incentives to take care, consider first each manufacturer's incentive to take care, given that the other manufacturer is careless. By taking care, a manufacturer reduces expected harm by 20 (from 40 to 20), but his liability share is reduced by only 13⅓ (from 20 to 6⅔). The difference between the reduction in expected harm and the manufacturer's saving in liability (6⅓ = 20 – 13⅓) constitutes a *positive*

22 In a mixed-strategy equilibrium, each manufacturer is indifferent between taking care and taking no care. It follows that each manufacturer's equilibrium payoff is equal to his payoff from taking no care, given that the other manufacturer takes care with the mixed-strategy equilibrium probability. Because efficiency requires that one manufacturer should take care and the other not, social welfare in the mixed-strategy equilibrium is lower than that which obtains when one manufacturer takes care and the other does not.

externality that a careful manufacturer confers on a careless one (note that the careless manufacturer's costs decrease by 6⅓ — from 20 to 13⅔ — as the other manufacturer takes care). Because the decrease in liability due to taking care is lower than the corresponding decrease in expected harm, the manufacturers have insufficient incentives to take care.

Consider next each manufacturer's incentive to take care, given that the other manufacturer is careful. By choosing to take no care, a manufacturer increases expected harm by 10 (from 10 to 20), but his liability share increases by only 8⅓ (from 5 to 13⅓). The difference between the increase in expected harm and the increase in the manufacturer's liability (1⅔ = 10 – 8⅓) constitutes a *negative externality* that a careless manufacturer confers on a careful one (note that the careful manufacturer's overall costs increase by 1⅔ — from 5 to 6⅔ — as the other manufacturer chooses no care over care). Because the increase in liability due to taking no care is lower than the corresponding increase in expected harm, manufacturers have insufficient incentives to take care.

C. Complementary Precautions

In this Section, we examine the manufactures' incentives to take care when their precautions are *complements* in preventing harm.[23] Imagine, again, that a certain consumer product consists of two components, each produced by a different manufacturer. Assume, as in the previous Section, that the probability of a defective product is reduced from ⅔ to ⅓ by taking care, and that, if harm occurs, consumers' loss is 90. Unlike in the previous Section, however, suppose now that consumers of the end-product will suffer harm if (at least) *one* component is defective. That is, harm will occur if either manufacturer (or both) produces a defective component. The following table summarizes the probability of harm and expected harm as functions of each manufacturer's level of care:

Table 4: Probability of Harm and Expected Harm (Complementary Precautions)

Manufacturers' Care Levels	Prob. of Harm	Expected Harm
Both take no care	$\frac{8}{9}$ $(1 - \frac{1}{3} \times \frac{1}{3})$	80
One takes care, one does not	$\frac{7}{9}$ $(1 - \frac{1}{3} \times \frac{2}{3})$	70
Both take care	$\frac{5}{9}$ $(1 - \frac{2}{3} \times \frac{2}{3})$	50

23 We use the term "complements" in a *narrow* sense (which we define below), rather than to capture generally positive cross-effects between the manufacturers' precautions.

Consider first the case in which both manufacturers are careless. Because the probability that each manufacturer will produce a non-defective component is $\frac{1}{3}$, the overall probability that the end-product will be safe is $\frac{1}{9}$ ($\frac{1}{3} \times \frac{1}{3}$). There is therefore a probability of $\frac{8}{9}$ that the end-product will cause harm to consumers. Next, if one manufacturer is careful and the other is careless, there is a probability of $\frac{2}{3}$ that one component will be safe and a probability of $\frac{1}{3}$ that the other component will be safe. The probability that the end-product will be safe is thus $\frac{2}{9}$ ($\frac{2}{3} \times \frac{1}{3}$). There is, therefore, a probability of $\frac{7}{9}$ that the end-product will cause harm to consumers. Finally, when both manufacturers are careful, there is a probability of $\frac{2}{3}$ that each manufacturer will produce a safe component. The probability that the end-product will be safe is therefore $\frac{4}{9}$ ($\frac{2}{3} \times \frac{2}{3}$), which implies that there is a probability of $\frac{5}{9}$ that the end-product will cause harm to consumers.[24]

As Table 4 shows, because *any* one defective component causes harm — regardless of the other component's quality — the benefit from one manufacturer's care is now lower when the other manufacturer is careless. If one manufacturer is careless, the other manufacturer saves only 10 in expected harm by being careful (by reducing the expected harm from 80 to 70). If one manufacturer is careful, however, the other manufacturer saves 20 in expected harm by being careful (by reducing the expected harm from 70 to 50). This result (of a higher marginal return for higher care levels) stems from the complementarity between the manufacturers' precautions. Because any one defective component causes harm, a low level of care by one manufacturer renders the other manufacturer's choice of care less pivotal. Given that one manufacturer is careless, the other manufacturer's choice of care has relatively little effect on expected harm. If one manufacturer takes care, however, the other manufacturer's choice of care becomes more pivotal, because taking care now significantly reduces expected harm. The essential feature of complementary precautions that affects injurers' incentives under a proportional allocation of liability, however, is that a decrease of 50% of each component's probability of being defective (from $\frac{2}{3}$ to $\frac{1}{3}$) reduces expected

24 In calculating the probability of harm, we implicitly invoked De Morgan's Law, whereby $\overline{A \cup B} = \bar{A} \cap \bar{B}$, which implies (after taking the complement of both sides) that $A \cup B = \overline{\bar{A} \cap \bar{B}}$. This identity means that the union of A and B is the complement of the intersection of A complement and B complement. In other words, the event that either event A or event B occurs is the complement of the event that both the complement event of A and the complement event of B occur. Here, harm occurs if either component is defective. Therefore, by De Morgan's Law, the event that harm occurs is the complement of the event that both components are non-defective.

harm by *less* than 50% (from 80 to 50). This implies that the harm-reducing technology exhibits *decreasing returns to scale*.

We now turn to examining the manufacturers' incentives to take care under a strict liability regime (with a proportional-allocation rule). As in the previous Section, we assume that the cost of care is 16. It is easy to see that it is undesirable, from a social perspective, for both manufacturers to take care. This is because the saving in expected harm (the difference of 30 between 80 and 50) when both manufacturers take care falls short of their total costs of care of 32 (16 + 16). It is inefficient, likewise, for only one manufacturer to take care because a manufacturer reduces the expected harm by 10 by being careful (from 80 to 70), which is less than each manufacturer's cost of care (16). Accordingly, social welfare is maximized when both manufacturers take no care.

Although efficiency requires that both manufacturers should take no care, each manufacturer, acting strategically, would prefer to take care. Interestingly, whereas strategic considerations cause the manufacturers to take too *little* care when their precautions are substitutes, they induce them to take too *much* care when their precautions are complements. The matrix in Table 5, which presents the manufacturers' payoffs under the four possible combinations of care levels, shows the strategic advantage of choosing to take care.[25]

25 We assume that consumers who suffer harm can collect damages from each manufacturer, even without proving which manufacturer's component was defective. This would be the case if the manufacturers collaborate as a "joint enterprise" and are therefore jointly liable for consumers' harm. *See* Dobbs, Hayden & Bublick, *supra* note 1, § 435. If the manufacturers do not collaborate, consumers must establish a causal connection between their harm and each manufacturer's conduct by showing that a manufacturer's component — rather than other manufacturers' components — was in fact defective (or that all manufacturers' components were defective). *See* Restatement (Third) of Torts: Products Liability § 5 (2012) (a manufacturer of a component is liable only if his "component is defective in itself"). However, our claim is in fact stronger under such a liability regime. As we later show, our results would continue to hold, and with greater force, if manufacturers are liable only if their own component is defective. *See infra* note 29.

Table 5: Manufacturer A's Payments
(Complementary Precautions; Cost of Care Equals 16)

		Manufacturer B	
		Care	No Care
Manufacturer A	Care	41	39⅓
	No Care	46⅔	40

If the manufacturers choose the same level of care — either carelessness or carefulness — they share equally in the responsibility for the occurrence of harm and therefore must share equally in the liability for consumers' harm. Accordingly, if both manufacturers are careless, each manufacturer faces an expected liability of 40 (½ × 80), but bears no cost of care.[26] If both manufacturers are careful, each manufacturer faces an expected liability of 25 (½ × 50) and pays 16 for the cost of care, for a total of 41. If the manufacturers choose different levels of care, then the careful manufacturer is liable for ⅓ of the harm and the careless manufacturer is liable for ⅔. Consequently, the careful manufacturer's expected costs are 39⅓ (16 + ⅓ × 70), whereas the careless manufacturer's expected costs are 46⅔ (⅔ × 700).

As the matrix in Table 5 shows, taking care is each manufacturer's best response to *any* choice of care by the other manufacturer. Although taking care is each manufacturer's dominant strategy, the resulting equilibrium fails to maximize the manufacturers' joint payoff (and hence social welfare). If both manufacturers take care, each bears costs of 41. If both instead take no care, each manufacturer's costs are only 40. Given that one manufacturer is careless, however, the other manufacturer's best response is to take care, because it reduces his overall costs to 39⅓. The manufacturers' payoff matrix is thus structurally equivalent to that of a "Prisoners' Dilemma," in which the unique equilibrium is detrimental to both players. This state of affairs, in which both manufacturers take care, is thus socially inefficient. Social costs

26 Note that given that each defective component is sufficient to cause harm, neither manufacturer is the "but-for cause" for the harm if both components are defective. The rule in cases of duplicative causation, however, is that defendants are jointly liable. Restatement (Third) of Torts: Liability for Physical and Emotional Harm § 27 (2011); *see also* Dobbs, Hayden & Bublick, *supra* note 1, § 189. Accordingly, when both components are defective, both manufacturers are liable and the rule of proportional liability determines each manufacturer's share of the total damages.

when both manufacturers are careful are 82, compared to only 80 when both are careless.

We can now consider the more general case in which each manufacturer's cost of care is *c*. Recall that when both manufacturers take care, the expected harm is reduced from 80 to 50. Accordingly, if *c* is less than (or equal to) 15, efficiency requires that both manufacturers should take care. If *c* is greater than 15, by contrast, no manufacturer should take care because the cost of care of any one manufacturer exceeds the corresponding saving in expected harm.[27] Under a proportional-allocation rule, however, the manufacturers have excessive incentives to take care. To see this, consider manufacturer A's payoff as a function of each manufacturer's level of care:

Table 6: Manufacturer A's Payments (Complementary Precautions; General Case)

		Manufacturer B	
		Care	No Care
Manufacturer A	Care	25 + c	23⅓ + c
	No Care	46⅔	40

Each manufacturer's dominant strategy is to take care if *c* is less than 16⅔. For such values of *c*, each manufacturer minimizes his costs by taking care, irrespective of the other manufacturer's choice of care (note that, for *c* less than 16⅔, 25 + *c* is less than 46⅔, and 23⅓ + *c* is less than 40). Similarly, each manufacturer's dominant strategy is to take *no* care, if *c* is greater than 21⅔. For such values of *c*, each manufacturer minimizes his costs by not taking care, irrespective of the other manufacturer's choice of care (note that, for *c* greater than 21⅔, 25 + *c* is greater than 46⅔, and 23⅓ + *c* is greater than 40). Finally, for values of *c* between 16⅔ and 21⅔, each manufacturer minimizes his costs by *mimicking* the choice of care of the other manufacturer (because, for *c* between 16⅔ and 21⅔, 25 + *c* is lower than 46⅔, but 23⅓ + *c* is greater than 40). The manufacturers minimize their aggregate costs of care and expected liability — and thus maximize social welfare — by coordinating on a no-care equilibrium.

27 Recall that when only one manufacturer takes care, the expected harm is reduced from 80 to 70. Accordingly, as long as the manufacturers' costs of care are identical, it is never socially optimal for only one of them to take care. To keep the analysis simple, we assume that *c* does not take threshold values. In the Appendix, we adopt a tie-breaking rule to resolve ties.

It is now clear that, given each manufacturer's best response to the other's choice of care, the manufacturers have excessive incentives to take care for *c* between 15 and 16⅔. For such values of *c*, although efficiency requires that both manufacturers should take no care, each manufacturer's dominant strategy is, in fact, to take care. For values of *c* between 16⅔ and 21⅔, efficiency (again) requires that no manufacturer should take care, but the manufacturers must coordinate on taking no care. In the absence of coordination, manufacturers are likely to randomize (in equilibrium) between taking care and taking no care.[28] Apportioning damages between the manufacturers according to the relative safety of their components thus results in an *intensification of liability*.

As in the case of substitute precautions, the distortion of the manufacturers' incentives stems from the difference between the social benefit from taking care and the manufacturers' corresponding private benefit. To understand why a proportional allocation of liability *boosts* manufacturers' incentives to take care, consider first each manufacturer's incentive to take care, given that the other manufacturer is careless. By taking care, a manufacturer reduces expected harm by only 10 (from 80 to 70), but his liability share is reduced by 16⅔ (from 40 to 23⅓). The difference between the saving in liability and the reduction in expected harm (6⅔ = 16⅔ – 10) constitutes a *negative externality* that a careful manufacturer confers on a careless one (note that the careless manufacturer's overall costs increase by 6⅓ — from 40 to 46⅔ — as the other manufacturer chooses care over no care). Because the decrease in liability from taking care is greater than the corresponding decrease in expected harm, manufacturers have excessive incentives to take care.

Consider next each manufacturer's incentive to take no care, given that the other manufacturer is careful. By choosing to take no care, a manufacturer increases expected harm by 20 (from 50 to 70), but his liability share increases by 21⅔ (from 25 to 46⅔). The difference between the increase in liability and the increase in expected harm (1⅔ = 21⅔ – 20) constitutes a *positive externality* that a careless manufacturer confers on a careful manufacturer (note that the careful manufacturer's overall costs decrease by 1⅔ — from 25 + *c* to 23⅓ + *c* — as the other manufacturer chooses care over no care). Because the increase in liability due to taking no care is greater than the

28 In a mixed-strategy equilibrium, each manufacturer is indifferent between taking care and taking no care. It follows that each manufacturer's equilibrium payoff is equal to his payoff from taking no care, given that the other manufacturer takes care with a probability given by the mixed-strategy equilibrium. Because the socially optimal outcome requires that no manufacturer should take care, social welfare in the mixed-strategy equilibrium is thus lower than that which obtains when one manufacturer takes care and the other does not.

corresponding increase in expected harm, manufacturers have excessive incentives to take precaution.[29]

29 Our result would be even stronger if we assumed that a manufacturer is only liable for consumers' harm if his component is in fact defective. To see this, suppose that, irrespective of the manufacturers' choice of care, if one manufacturer's component is defective and the other's is not, the first manufacturer is liable for the entire harm and the second manufacturer is exempt from liability. Note, first, that each manufacturer's expected liability, when both manufacturers are either careful or careless, remains the same. In particular, each manufacturer's liability, if both manufacturers are careful, is ⅓ × [⅓ × ½ × 90 + ⅔ × 90], which is equal to 25. The fraction ⅓, outside the square brackets, represents the probability that the manufacturer's component will be defective. The first term in the square brackets is the probability that the other manufacturer's component will be defective (⅓) times the manufacturer's liability share (½) times the harm (90); the second term in the square brackets is the probability that the other manufacturer's component will not be defective (⅔) times the entire harm (90). Similarly, each manufacturer's liability, if both manufacturers are careless, is ⅔ × [⅔ × ½ × 90 + ⅓ × 90], which is equal to 40.
Next, if one manufacturer is careful and the other is careless, the careful manufacturer's expected liability is ⅓ × [⅔ × ⅓ × 90 + ⅓ × 90], which is equal to 16⅔. The first term in the square brackets is the probability that the other (careless) manufacturer's component will be defective (⅔) times the careless manufacturer's share (⅓) times the harm (90); the second term is the probability that the other (careless) manufacturer's component will not be defective times the harm (90). Because the expected harm, when one manufacturer is careful and the other is careless, is 70, it follows that the careless manufacturer's expected liability is 53⅓ (difference between 70 and 16⅔). The row manufacturer's liability matrix is therefore:

	Care	No Care
Care	25 + *c*	16⅔ + *c*
No Care	53⅓	40

Each manufacturer's dominant strategy is thus to take care if *c* is less than 23⅓, to take no care if *c* is greater than 28⅓, and to mimic the other manufacturer's choice of care if *c* is between 23⅓ and 28⅓. Note that each manufacturer's incentive to take (excessive) care is greater in this case than in that described in the text, in which victims need not show which manufacturer's component is defective.

II. Discussion

This Part considers the normative and strategic implications of our analysis. In Section A, we discuss the implications of our analysis for the possibility of achieving equity[30] and efficiency under a proportional allocation of liability. We then characterize, in Section B, the strategic nature of injurers' interactions under different precaution technologies and thereby shed further light on the distortions caused by a proportional allocation of liability. Finally, Section C extends the analysis to the case in which the manufacturers take actions in sequence and demonstrates that, although inefficiencies resulting from mis-coordination no longer exist, those created by strategic conflict remain.

A. Equity Versus Efficiency

The previous Part exposed the divergence between the social benefit from each manufacturer's taking care (lower expected harm) and the corresponding private benefit (lower expected liability) under a proportional allocation rule. This divergence between the private and the social benefit from taking care suggests that manufacturers' liability should be based on their actual contribution to the reduction in expected harm, rather than on their relative levels of care. This means that, if precautions are substitutes, the allocation of liability between a careful and a careless manufacturer should be biased in favor of the careful manufacturer. If precautions are complements, by contrast, the allocation rule should be tilted in favor of the careless manufacturer.

Specifically, to implement the socially optimal choice of care when precautions are *substitutes*, a careless manufacturer should be liable for 15 (instead of 13⅓) and a careful manufacturer should be liable for 5 (instead of 6⅔), if the cost of care is between 8⅔ and 15.[31] Under this allocation of liability, it is a dominant strategy for each manufacturer to take care if the cost of care is between 8⅔ and 10 (because for c between 8⅔ and 10, $5 + c < 15$). If the cost of care is between 10 and 15, each manufacturer's best response is to take the opposite action to that taken by the other manufacturer (because for c between 10 and 15, $5 + c < 15$, but $5 + c < 20$).

If the cost of care is between 15 and 20, a careless manufacturer should be liable for 20 (the entire harm), whereas a careful manufacturer should

30 We use the terms "equity" and "fairness" interchangeably.

31 Under this allocation, manufacturer A's liability for c between 8⅔ and 10 is:

	Care	No Care
Care	$5 + c$	$5 + c$
No Care	15	20

be exempt from liability altogether.[32] Under this allocation of liability, each manufacturer's best response is to take care if the other manufacturer is careless and to take no care if the other manufacturer is careful (because for c between 15 and 20, $20 < 5 + c$, but $c < 20$). Although manufacturers still face a coordination problem, there is no equilibrium in which both manufacturers are careless for c between 13⅓ and 20, as under a proportional allocation rule. Moreover, when manufacturers take actions in sequence, the unique equilibrium coincides with the socially optimal outcome.[33]

To implement the socially optimal choice of care when precautions are *complements*, a careless manufacturer should be liable for 45 (instead of 46⅔) and a careful manufacturer should be liable for 25 (instead of 23⅓) if the cost of care is between 15 and 16⅔.[34] Under this allocation of liability, it is no longer a dominant strategy for each manufacturer to take care if the cost of care is between 15 and 16⅔, as under a proportional-allocation rule. Although manufacturers face a coordination problem (because for c between 15 and 16⅔, $25 + c < 45$, but $40 < 25 + c$), this coordination problem vanishes when manufacturers take actions in sequence.[35]

Whether injurers' precautions are substitutes or complements, however, seems to have little bearing on the issue of the equitable allocation of liability. A manufacturer's decision to take no care increases the probability that his component will be defective by ⅓, irrespective of the interplay between the manufacturers' precautions. Because victims' potential harm is the same in both cases (90), the different consequences of a manufacturer's carelessness with respect to the increase in expected harm are due only to the nature of the manufacturers' precautions (substitutes or complements). From a fairness perspective, which focuses on injurers' individual responsibility, however, the nature of the interaction between injurers' precautions should play no role in the allocation of liability. Whereas manufacturers fully control the safety

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32 Under this allocation, manufacturer A's liability for c between 10 and 20 is:

	Care	No Care
Care	$5 + c$	c
No Care	20	20

33 *See infra* Section II.C.

34 Under this allocation, manufacturer A's liability for c between 15 and 16⅔ is:

	Care	No Care
Care	$25 + c$	$25 + c$
No Care	45	40

35 *See infra* Section II.C.

of their respective component, they exert no such control over the interplay between their precautions and those taken or not taken by others. Thus, it is the manufacturers' relative levels of care, rather than the interplay between their precautions, that should decide each injurer's equitable share of liability.

The upshot of the preceding analysis is that if precautions are either substitutes or complements, a proportional allocation of liability fails to achieve efficiency. Proportionality requires that injurers' liability be based on their relative care levels. Thus if one manufacturer's component is twice as likely to be defective as the other's, the former manufacturer's liability share should be twice that of the latter's. From an efficiency perspective, however, the allocation of liability must depend on the interaction between the manufacturers' precautions. In particular, the allocation of liability should be tilted in favor of the careless manufacturer (relative to a proportional allocation) if precautions are complements and in favor of the careful one if precautions are substitutes. Applying proportionality as a fairness standard therefore entails an inevitable loss of social welfare.

B. Free-Riding Versus Rent-Seeking

The effects of a proportional allocation of liability on the incentives to take care depend, as previously demonstrated, on the cost of care, as well as on manufacturers' precaution technology (substitutes or complements). To shed further light on the distortion of manufacturers' incentives under a proportional allocation rule, we characterize the nature of the strategic interaction induced by such a rule for different costs of care and different precaution technologies.

Consider first the case of substitute precautions. If the cost of care is low (between 8⅓ and 10) or high (between 13⅔ and 20), each manufacturer's effort to minimize his cost of care and expected liability engenders a *free-rider problem*. In particular, recall that each manufacturer would prefer to take no care, given that the other manufacturer is careful, if the cost of care is low; and would prefer to take no care, irrespective of the other manufacturer's choice of care, if the cost of care is high. Under the socially optimal choice of care, by contrast, both manufacturers should take care for a low cost of care, and only one manufacturer should take care for a high cost of care. Manufacturers fail to minimize their joint costs — and thereby fail to maximize social welfare — because each has incentives to *free ride* on the other manufacturer's efforts to take care.

If the cost of care is intermediate (between 10 and 13⅔), however, manufacturers face a *coordination problem*. In particular, manufacturers minimize their joint costs — and therefore increase social welfare — by having one manufacturer take care and the other take no care. However, because the total costs of a careful manufacturer exceed those of a careless one, manufacturers must coordinate on an asymmetric strategy profile. Although both manufacturers benefit from choosing opposite actions, they might not agree on which manufacturer should take care (in the presence of coordination costs). Free-riding might again frustrate the attainment of an efficient outcome.[36]

Next, consider the case of complementary precautions. If the cost of care is low (between 15 and 16⅔), each manufacturer's effort to minimize his cost of care and expected liability engenders a *rent-seeking problem*. In a pure rent-seeking game, players expend effort to increase their share of a fixed prize. Effort is thus incurred not to increase welfare, but to increase a player's own share at the expense of the other player. A proportional allocation rule for complementary precautions engenders a similar competition over a negative prize: the payment of damages to victims. Each manufacturer accordingly has incentives to increase his level of care, merely to shift a greater liability share on to the other player, rather than to decrease expected harm.[37] The competition to externalize liability shares induces manufacturers to take too much care.

If the cost of care is high (16⅔ and 21⅔), by contrast, manufacturers face a *coordination problem* (similar to the one manufacturers face when their precautions are substitutes and each manufacturer's cost of care is intermediate).

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36 Manufacturers will not always face such a coordination problem when their precautions are substitutes. To see this, suppose that by taking care each manufacturer reduces the probability that his component will be defective from $^{7}/_{12}$ to $^{5}/_{12}$. Suppose further that if the harm occurs, consumers suffer a loss of 1,728. The row manufacturer's liability matrix is:

	Care	No Care
Care	$150 + c$	$175 + c$
No Care	245	294

In this case, each manufacturer's dominant strategy is to take care if $c < 95$ and to take no care if $c > 119$. On the other hand, efficiency requires that both manufacturers should take care if $c < 120$, and that one manufacturer should take care if $120 < c < 168$. In this example, therefore, there is no range of c values in which it is optimal for only one manufacturer to take care, and manufacturers can coordinate on such an equilibrium. Rather, each manufacturer has a dominant strategy of taking no care for any value of c, for which it is optimal for only one manufacturer to take care. For a more complete treatment of the divergence between the private and the social incentives to take care, see Corollary 1 in the Appendix.

37 A manufacturer's taking care reduces expected harm by 15 given that the other manufacturer takes care as well (the difference between 80 and 30), but the reduction in the manufacturer's liability due to unilaterally taking care is 16⅔ (the difference between 40 and 23⅓).

Manufacturers' payoffs are maximized if neither takes care, but each would prefer to take care if the other manufacturer takes care as well. The underlying strategic interaction between the manufacturers is equivalent to an arms-race game (or equivalently, a stag-hunt game). Each player in an arms-race game would prefer not to acquire weapons if the other player remains unarmed, but prefers to be armed if the other player is armed. Players could profit from coordinating on a non-armament equilibrium, which is resistant to unilateral deviation. Similarly, in the present case, each manufacturer would prefer to take no care, if the other manufacturer is careless, but otherwise would prefer to take care. Coordinating on a no-care equilibrium thus maximizes each player's payoff.

In summary, a proportional allocation induces different types of strategic behavior, depending on the nature of the manufacturers' precautions. If precautions are substitutes, a proportional allocation induces free riding for either a low or high cost of care (and a coordination problem for an intermediate cost). If precautions are complements, by contrast, a proportional allocation fosters rent-seeking for a low cost of care (and a coordination problem for a high cost). As a result of these strategic behaviors, manufacturers fail to maximize social welfare, as well as their own payoffs. As we show in the next Section, these inefficiencies persist even when manufacturers choose their actions sequentially.

C. Simultaneous- Versus Sequential-Move Game

Thus far, we have considered a simultaneous-move game, in which each manufacturer chooses his level of care without observing the other manufacturer's choice of care. We now show that a proportional allocation of liability distorts manufacturers' incentives to take care, even if they take actions sequentially. Unlike the simultaneous-move case, however, manufacturers are better able to coordinate their actions if they move one after the other. Consequently, inefficiencies that arise from mis-coordination do not occur. By contrast, inefficiencies that result from the injurers' strategic behavior remain, even if moves are made sequentially.

Suppose that one manufacturer ("manufacturer 1") first chooses whether or not to take care. After having observed manufacturer 1's decision, the other manufacturer ("manufacturer 2") then decides whether or not to take care. To find the manufacturers' equilibrium strategies, we consider first manufacturer 2's optimal choice of care for any choice of care by manufacturer 1. We then consider manufacturer 1's choice of care given manufacturer 2's anticipated response.

We begin with the case of substitute precautions.[38] Recall that, in a simultaneous-move game, each manufacturer's dominant strategy is to take care for low values of c ($c < 8⅓$) and to take no care for high values of c ($c > 13⅓$). For intermediate values of c ($8⅓ < c < 13⅓$), each manufacturer maximizes his payoff by taking the action opposite to that of the other manufacturer (i.e., taking care if the other manufacturer takes no care and vice versa). This, in turn, implies that, in a sequential-move game, manufacturer 2 takes care for any choice of care by manufacturer 1 for low values of c; takes no care for any choice of care by manufacturer 1 for high values of c; and takes care if manufacturer 1 took no care and vice versa for intermediate values of c.

We can now find manufacturer 1's optimal choice of care. For low values of c ($c < 8⅓$), manufacturer 2's best response is to take care, irrespective of manufacturer 1's choice of care. Thus manufacturer 1 obtains $5 + c$, if he takes care, and 13⅓, if he takes no care. Because $5 + c$ is less than 13⅓ for any c less than 8⅓, manufacturer 1 is better off taking care than taking no care.

For high values of c ($c > 13⅓$), manufacturer 2's best response is to take no care, irrespective of manufacturer 1's choice of care. Thus manufacturer 1 obtains $6⅔ + c$, if he takes care, and 20, if he takes no care. Because 20 is less than $6⅔ + c$ for any c greater than 13⅓, manufacturer 1 is better off taking no care than taking care.

Finally, for intermediate values of c ($8⅓ < c < 13⅓$), manufacturer 1 obtains 13⅓ if he takes no care (because manufacturer 2 will then take care) and $6⅔ + c$ if he takes care (because manufacturer 2 will then take no care). Because 13⅓ is less than $6⅔ + c$ for any c between 8⅓ and 13⅓, manufacturer 1 is better off taking no care than taking care.

The equilibrium outcome of a sequential-move game is thus identical to that of a simultaneous-move game, except when the cost of care is intermediate (c between 10 and 13⅓). In both games, manufacturers take too little care for values of c between 8⅓ and 10 and between 13⅓ and 20 (recall that efficiency requires that both manufacturers should take care if c is less than 10 and that one manufacturer should take care if c is between 10 and 20). For intermediate values of care (c between 10 and 13⅓), however, the manufacturers are better able to coordinate their actions if they move in sequence. This follows because the first manufacturer can anticipate the second manufacturer's best response and will therefore choose to take no care. Following manufacturer 1's decision to take no care, manufacturer 2 will choose to take care. Manufacturer 1 thus enjoys a *first-mover advantage*. By taking no care, manufacturer 1 induces manufacturer 2 to take care.

38 *See supra* Table 3.

We turn to the case of complementary precautions.[39] Recall that, in a simultaneous-move game, each manufacturer's dominant strategy is to take care for low values of c ($c < 16⅔$) and to take no care for high values of c ($c > 21⅔$). For intermediate values of c ($16⅔ < c < 21⅔$), each manufacturer's best response is to mimic the other manufacturer's choice of care (i.e., take care if the other manufacturer takes care and take no care otherwise). This, in turn, implies that, in a sequential-move game, manufacturer 2 takes care for any choice of care by manufacturer 1 for low values of c; takes no care for any choice of care by manufacturer 1 for high values of c; and takes care if manufacturer 1 took care and takes no care if manufacturer 1 took no care for intermediate values of c.

We can now proceed to finding manufacturer 1's optimal choice of care. For low values of c ($c < 16⅔$), manufacturer 2's best response to any choice of care by manufacturer 1 is to take care. Thus manufacturer 1 obtains 25 + c if he takes care and 46⅔ if he takes no care. Because 25 + c is less than 46⅔ for any c less than 16⅔, manufacturer 1 is better off taking care than taking no care.

For high values of c ($c > 21⅔$), manufacturer 2's best response to any choice of care by manufacturer 1 is to take no care. Thus manufacturer 1 obtains 23⅔ + c if he takes care and 40 if he takes no care. Because 40 is less than 23⅔ + c for any c greater than 21⅔, manufacturer 1 is better off taking no care than taking care.

Finally, for intermediate values of c ($16⅔ < c < 21⅔$), manufacturer 1 obtains 40 if he takes no care (because manufacturer 2 will take no care as well) and 25 + c if he takes care (because manufacturer 2 will take care as well). Because 40 is less than 5 + c for any c between 16⅔ and 21⅔, manufacturer 1 would prefer to take no care than to take care. Following manufacturer 1's decision to take no care, manufacturer 2 will choose to take no care as well.

The equilibrium outcome of a sequential-move game is thus identical to that of a simultaneous-move game, except when the cost of care, c, takes intermediate values (i.e., c between 16⅔ and 21⅔). In both games, manufacturers take too much care if c is between 15 and 16⅔ (recall that efficiency requires that both manufacturers should take care if c is less than 15). For intermediate values of the cost of care, however, manufacturers are better able to coordinate their actions if they move in sequence. This follows because the first manufacturer can anticipate the second manufacturer's best response and will therefore choose to take no care.

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39 *See supra* Table 6.

Conclusion

In this Article, we have considered the strategic effects of a proportional allocation of strict liability on injurers' incentives to take care. We presented a stylized example involving two injurers, who must each choose whether or not to take care. Injurers' precautions can be either substitutes or complements in preventing harm. If injurers' precautions are substitutes, harm occurs if both injurers' activities are (potentially) harmful. If precautions are complements, by contrast, harm occurs if one (or both) injurer's activity is (potentially) harmful.

We showed that a proportional allocation of liability distorts injurers' incentives to take care, depending on the nature of their precautions (substitutes or complements). In particular, irrespective of whether injurers take actions simultaneously or sequentially, they have incentives to take too little care if their precautions are substitutes and too much care if their precautions are complements. This distortion of injurers' incentives is a consequence of moral hazard, in the case of substitute precautions, and of rent seeking, in the case of complementary precautions.

The optimal allocation of liability, by contrast, is disproportionate. Thus liability should be tilted (relative to a proportional allocation) in favor of the careless injurer if precautions are complements and in favor of the careful one if precautions are substitutes. Resorting to proportionality as a standard for allocating liability between multiple injurers thus involves an inevitable tradeoff between equity and efficiency. Whereas proportionality requires that liability be based solely on agents' relative carelessness, efficiency often demands adjusting injurers' liability to the interplay between their precautions.

Appendix

This Appendix generalizes the Article's example.

Consider two manufacturers. Each manufacturer produces a component, which can be either defective or non-defective ("safe"). If a manufacturer takes no care, the component will be safe with a probability P_L. If a manufacturer spends c on care, the component will be safe with a probability P_H. We assume that $1 > P_H > P_L > 0$ so that taking care increases the probability that the component will be safe. We normalize the size of the harm to 1. Finally, we assume that, in case of a tie, each manufacturer would rather take care and the social planner would rather have the manufacturers take care.

Let $\Pi(. , .)$ represent the row manufacturer's liability under a proportional allocation rule as a function of his (first argument) and the column manufacturer's (second argument) strategy, as shown in the following matrix:

	I	N
I	$\Pi(I, I)$	$\Pi(I, N)$
N	$\Pi(N, I)$	$\Pi(N, N)$

For example, $\Pi(I, N)$ denotes the row manufacturer's liability when he takes care (I) and the column manufacturer takes no care (N).

The next Proposition considers each manufacturer's best response to the other manufacturer's choice of care (part (a)), as well as the socially optimal choice of care (part (b)) for different costs of care.

Proposition 1 (Substitute Precautions)

Suppose that precautions are perfect substitutes so that the probability of harm is $(1 - P_1)(1 - P_2)$, where $P_i \in \{P_L, P_H\}$ for i = 1, 2.

Let $C_L \equiv \Pi(N, I) - \Pi(I, I)$, $C_H \equiv \Pi(N, N) - \Pi(I, N)$, $C^*_L \equiv \Pi(N, I) + \Pi(I, N) - 2\Pi(I, I)$, and $C^*_H \equiv 2\Pi(N, N) - [\Pi(N, I) + \Pi(I, N)]$.

(a) (best response)

Each manufacturer's dominant strategy is to take care if $c \leq C_L$ and to take no care if $c > C_H$. If $C_L < c \leq C_H$, each manufacturer's best response is to take care if the other manufacturer takes no care and vice versa.

(b) (social optimum)

To maximize social welfare, both manufacturers should take care if $c \leq C^*_L$, where $C^*_L > C_L$ and should take no care if $c > C^*_H$, where $C^*_H > C_H$. If $C^*_L < c \leq C^*_H$, one manufacturer should take care and the other should take no care.

Proof.

Before proceeding to the proof, let us present the row manufacturer's *liability matrix* under a proportional allocation rule:

	I	N
I	$\frac{1}{2}(1 - P_H)^2$	$(1 - P_H) / (2 - P_L - P_H) \times (1 - P_H)(1 - P_L)$
N	$(1 - P_L) / (2 - P_L - P_H) \times (1 - P_H)(1 - P_L)$	$\frac{1}{2}(1 - P_L)^2$

We begin by showing that the relative size of the row manufacturer's liability is as follows:

	I	N
I	A	B
N	C	D

where D > C > B > A.

First, consider the relationship between $\Pi(I, N)$ and $\Pi(I, I)$ (that is, B and A, respectively). Note that $P_H > P_L$ implies that $(1 - P_L) / (2 - P_L - P_H) > ½$. Multiplying through by $(1 - P_H)^2$ gives $B \equiv [(1 - P_H) / (2 - P_L - P_H)] \times (1 - P_H)(1 - P_L) > ½(1 - P_H)^2 \equiv A$. The fact that B > A means that, given that both manufacturers take care, a manufacturer that deviates to taking no care imposes a *negative* externality on the other manufacturer.

Next, consider the relationship between $\Pi(N, I)$ and $\Pi(N, N)$ (that is D and C, respectively). Note that $P_H > P_L$ implies that $½ > (1 - P_H) / (2 - P_L - P_H)$. Multiplying through by $(1 - P_L)^2$ gives $D \equiv ½(1 - P_L)^2 > [(1 - P_L) / (2 - P_L - P_H)] \times (1 - P_H)(1 - P_L) \equiv C$. The fact that D > C means that, given that both manufacturers take no care, a manufacturer that deviates to taking care imposes a *positive* externality on the other manufacturer.

Finally, because B > A, D > C, and, for any proportional rule, C > B, we have that D > C > B > A.

The *general strategy* of the proof is as follows. We will show, in the proof of part (a), that the liability difference C – A ($\equiv C_L$) is smaller than the liability difference D – B ($\equiv C_H$). It is therefore a dominant strategy for each manufacturer to take care if $c \leq C_L$ and to take no care if $c > C_H$. For $C_L < c \leq C_H$, each manufacturer would rather take no care if the other manufacturer takes care (because for such values of c, the strong inequality $c > C - A \equiv C_L$ implies that $A + c < C$) and to take care if the other manufacturer takes no care (because for such values of c, the weak inequality $c \leq D - B \equiv C_H$ implies that $B + c \leq D$).

For part (b) we show that efficiency requires both manufacturers to take care if and only if c is lower than (or equal to) the liability difference (B + C) – 2A ($\equiv C^*_L$) and only one manufacturer to take care if c is lower than (or equal to) the liability difference 2D – (B + C) ($\equiv C^*_H$). We then establish the relationships between C_L, C_H, C^*_L, and C^*_H using the relationships B > A and D > C.

(a) We proceed by showing that $C_H \equiv \Pi(N, N) - \Pi(I, N) > \Pi(N, I) - \Pi(I, I) \equiv C_L$ (that is, D – B > C – A). This in turn implies that for $c \leq C_L$, each manufacturer's dominant strategy is to take care; that for $C > c_H$, each manufacturer's dominant strategy is to take no care; and that for $C_L \leq c < C_H$, each manufacturer's best response is to take the opposite action to the other manufacturer's action.

Now, $\Pi(N, I) + \Pi(I, N) = (1 - P_H)(1 - P_L)$ and $\Pi(N, N) + \Pi(I, I) = ½(1 - P_H)^2 + ½(1 - P_L)^2$. Subtracting the former expression from the latter gives $½P_H^2 + ½P_L^2 - P_H P_L$, which is equal to $½(P_H - P_L)^2 > 0$. This in turn implies that $\Pi(N, N) + \Pi(I, I) > \Pi(N, I) + \Pi(I, N)$ and therefore that $C_H \equiv \Pi(N, N) - \Pi(I, N) > \Pi(N, I) - \Pi(I, I) \equiv C_L$.

(b) The reduction in expected harm when only one manufacturer takes care is $C^*_H \equiv 2D - (B + C) = 2\Pi(N, N) - [\Pi(N, I) + \Pi(I, N)]$. This is equal to $(1 - P_L)^2 - (1 - P_H)(1 - P_L)$, which simplifies to $(1- P_L)(P_H - P_L)$.

The *additional* reduction in expected harm when two manufacturers take care is $C^*_L \equiv (B + C) - 2A = \Pi(N, I) + \Pi(I, N) - 2\Pi(I, I)$. This is equal to $(1 - P_H)(1 - P_L) - (1 - P_H)^2$, which simplifies to $(1- P_H)(P_H - P_L)$.

Now, because $(1- P_L)(P_H - P_L) > (1 - P_H)(P_H - P_L)$ (recall that $P_H > P_L$) it follows that the additional reduction in expected harm when one manufacturer takes care (C^*_H) is greater than when two manufacturers take care (C^*_L). Thus it is optimal for both manufacturers to take care if each manufacturer's cost of care, c, is lower than C^*_L; and for only one manufacturer to take care if each manufacturer's cost of care is lower than C^*_H but higher than C^*_L.

To show that $C_L > C^*_L$, recall that $B > A$ (that is $\Pi(I, N) > \Pi(I, I)$). Adding $C - 2A$ to both sides implies that $C^*_L \equiv B + C - 2A > C - A \equiv C_L$. Finally, to show that $C^*_H > C_H$, recall that $D > C$ (that is, $\Pi(N, I) > \Pi(N, N)$). Adding $D - (B + C)$ to both sides and rearranging yields that $C^*_H \equiv 2D - (B + C) > D - B \equiv C_H$.

Proposition 1 defines ranges of costs of care such that each manufacturer's dominant strategy is to take care ($c \leq C_L$), each manufacturer's dominant strategy is to take no care ($c > C_H$), and each manufacturer's best response is to choose an opposite action to that of the other manufacturer ($C_L < c \leq C_H$). It also defines ranges of costs of care such that both manufacturers should take care ($c \leq C^*_L$), no manufacturer should take care ($c > C^*_H$), and only one manufacturer should take care ($C^*_L < c \leq C^*_H$). The next Corollary considers the divergence between the equilibrium and the socially optimal outcomes.

Corollary 1

(Divergence between social optimum and equilibrium outcome for substitute precautions).

Case i. Suppose $C_L < C^*_L < C_H < C^*_H$.

(a) If $C_L < c \leq C^*_L$, there is no equilibrium in which both manufacturers take care, although efficiency requires that both should.

(b) If $C^*_L < c \leq C_H$, manufacturers face a coordination problem: efficiency requires that one manufacturer should take care, but each manufacturer would rather take no care if the other manufacturer takes care and vice versa.

(c) If $C_H < c \leq C^*_H$, no manufacturer takes care in equilibrium, although efficiency requires that one manufacturer should.

Case ii: Suppose $C_L < C_H < C^*_L < C^*_H$.

(a) If $C_L < c \leq C_L$, there is no equilibrium in which both manufacturers take care, although efficiency requires that both manufacturers should take care.

(b) If $C_H < c \leq C^*_L$, no manufacturer takes care in equilibrium, although efficiency requires that both manufacturers should take care.

(c) If $C^*_L < c \leq C^*_H$, no manufacturer takes care in equilibrium, although efficiency requires that one manufacturer should take care.

The example in the text illustrates the divergence between the equilibrium and socially optimal outcome in *Case i*. The example in footnote 36 illustrates the divergence between the equilibrium and socially optimal outcome in *Case ii*.

We turn now to complementary precautions. The next Proposition considers each manufacturer's best response to the other manufacturer's choice of care (part (a)), as well as the socially optimal choice of care (part (b)), as a function of manufacturers' cost of care.

Proposition 2 (Complementary Precautions)

Suppose precautions are perfect complements so that the probability of harm is $1 - P_1P_2$, where $P_i \in \{P_L, P_H\}$ for i = 1, 2.

Let $C_L \equiv \Pi(N, N) - \Pi(I, N)$, $C_H \equiv \Pi(N, I) - \Pi(I, I)$, *and* $C^* \equiv \Pi(N, N) - \Pi(I, I)$.

(a) (best response)
Each manufacturer's dominant strategy is to take care if $c \leq C_L$ and to take no care if $c > C_H$. If $C_L < c \leq C_H$, each manufacturer would rather take care if the other manufacturer takes care and vice versa.

(b) (social optimum)
To maximize social welfare, both manufacturers should take care if $c \leq C^*$ and both manufacturers should take no care if $c > C^*$, where $C^* < C_L$.

Proof.

Consider the row manufacturer's liability matrix under a proportional liability rule:

	I	*N*
I	$\frac{1}{2}(1 - P_H^2)$	$(1 - P_H) / (2 - P_L - P_H) \times (1 - P_HP_L)$
N	$(1 - P_L) / (2 - P_L - P_H) \times (1 - P_HP_L)$	$\frac{1}{2}(1 - P_L^2)$

We begin by showing that the relative size of the row manufacturer's liability is as follows:

	I	*N*
I	B	A
N	D	C

where D > C > B > A.

First, consider the relationship between $\Pi(I, I)$ and $\Pi(I, N)$ (that is B and A, respectively). Note that that $(P_H - P_L)(1 - P_H) > 0$ implies that $P_H - P_H^2 - P_L > - P_H P_L$. Adding $2 - P_H P_L$ to both sides gives $2 + P_H - P_H^2 - P_L - P_H P_L > 2 - P_H P_L$, which can be written as $(1 + P_H)(2 - P_H - P_L) > 2 - P_H P_L$. Multiplying through by $(1 - P_H) / (2 - P_L - P_H)$ and rearranging gives $B \equiv ½(1 - P_H)^2 > (1 - P_H) / (2 - P_L - P_H) \times (1 - P_H P_L) \equiv A$. The fact that B > A means that, given that both manufacturers take care, a manufacturer that deviates to taking no care imposes a *positive* externality on the careless manufacturer.

Next, consider the relationship between $\Pi(N, I)$ and $\Pi(N, N)$ (that is D and C, respectively). Note that $(P_H - P_L)(1 - P_L)^2 > 0$ implies that $(P_H - P_L) - 2P_L(P_H - P_L) + P_L^2(P_H - P_L) > 0$. Rearranging terms and adding $2 - P_L + P_H P_L^2$ to both sides gives $2 - 2P_L - 2P_L P_H + 2P_H P_L^2 > 2 - P_H - P_L - 2P_L^2 + P_H P_L^2 + P_L^3$. Factoring each side we get $2(1 - P_L)(1 - P_L P_H) > (1 - P^2_L)(2 - P_H - P_L)$, which implies that $D \equiv ((1 - P_L) / (2 - P_L - P_H)) \times (1 - P_H P_L) > ½(1 - P_L)^2 \equiv C$. The fact that D > C means that, given that both manufacturers take no care, a manufacturer that deviates to taking care imposes a *negative* externality on the careless manufacturer.

Finally, because B > A, D > C, and, for any proportional rule, C > B, we have that D > C > B > A.

We will show, in the proof of part (a), that the liability difference D − B ($\equiv C_H$) is greater than the liability difference C − A ($\equiv C_L$). This implies that it is a dominant strategy for each manufacturer to take care if c is lower (or equal to) C_L and to take no care if c is greater than C_H. For $C_L < c \leq C_H$, each manufacturer would rather take no care if the other manufacturer takes no care as well (because for such values of c, the strong inequality $c > C - A \equiv C_L$ implies that $A + c > C$) and to take care if the other manufacturer takes care as well (because for such values of c, the weak inequality $c \leq D - B \equiv C_L$ implies that $B + c \geq D$).

For part (b) we will show that efficiency requires that both manufacturers should take care if and only if c is lower than (or equal to) the liability difference C − B. We then establish the relationship between C^* and C^*_L using the relationship B > A.

(a) We proceed by showing that $C_H \equiv \Pi(N, I) - \Pi(I, I) > \Pi(N, N) - \Pi(I, N) \equiv C_L$. This in turn implies that for $c \leq C_L$, each manufacturer's dominant strategy is to take care; that for $c > C_H$, each manufacturer's dominant strategy is to take no care; and that for $C_L < c \leq C_H$, each manufacturer's best response is to mimic the other's manufacturer's choice of care.

Now, $\Pi(N, I) + \Pi(I, N) = 1 - P_H P_L$ and $\Pi(N, N) + \Pi(I, I) = 1 - ½P_H^2 - ½P_L^2$. Subtracting the latter expression from the former gives $½P_H^2 + ½P_L^2 - P_H P_L$, which is equal to $½(P_H - P_L)^2 > 0$. This in turn implies that $\Pi(N, I) + \Pi(I, N) > \Pi(N, N) + \Pi(I, I)$ and therefore that $C_H \equiv \Pi(N, I) - \Pi(I, I) > \Pi(N, N) - \Pi(I, N) \equiv C_L$.

(b) The reduction in expected harm when only one manufacturer takes care is $(1 - P_L^2) - (1 - P_H P_L)$, which simplifies to $P_H P_L - P_L^2$. The *additional* reduction in expected harm when two manufacturers take care is $(1 - P_H P_L) - (1 - P_H^2)$, which simplifies to $P_H^2 - P_H P_L$. But $(P_H - P_L)^2 > 0$ implies that $P_H^2 - P_H P_L > P_H P_L - P_L^2$ and therefore that the additional reduction in the expected harm when one manufacturer takes care is lower than when two manufacturers take care. Thus it is optimal for both manufacturers to take care if the manufacturers' aggregate costs of care ($2c$) are lower than the *total* reduction in expected harm when both manufacturers take care. Because the total reduction in the expected harm when both manufacturers take care is $2[\Pi(N, N) - \Pi(I, I)]$, both manufacturers should take care if $c \leq \Pi(N, N) - \Pi(I, I) \equiv c^*$.

Finally, to show that $C^* < C_L$, recall that B > A (that is, $\Pi(I, I) > \Pi(I, N)$). This implies that C – B < C – A. But $C^* \equiv$ C – B and $C_L \equiv$ C – A. Therefore $C^* < C_L$. ■

Proposition 2 defines ranges of costs of care such that each manufacturer's dominant strategy is to take care ($c \leq C_L$), each manufacturer's dominant strategy is to take no care ($c > C_H$), and each manufacturer's best response is to mimic the other manufacturer's choice of care ($C_L < c \leq C_H$). It also defines ranges of costs of care such that both manufacturers should take care ($c \leq C^*$) or should take no care ($c > C^*$). The next Corollary considers the divergence between the equilibrium and the socially-optimal outcomes.

Corollary 2

(Divergence between social optimum and equilibrium outcome for complementary precautions)

(a) If $C^* < c \leq C_L$, both manufacturers take care in equilibrium although efficiency requires that none of them should take care.

(b) If $C_L < c \leq C_H$, manufacturers face a coordination problem: Although efficiency requires that none of them should take care, each manufacturer would rather take care if the other manufacturer takes care as well.