

INADEQUATE COMPENSATION AND MULTIPLE EQUILIBRIA*

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Abstract

This paper studies alternative care situations in which the injurer is liable for harm but the victim is only partially compensated for her losses, for example, because the accident will result in serious bodily injury or death. In these situations, liability gives rise to multiple equilibria, some of them inefficient. We analyze possible solutions to the multiple equilibria problem including precaution costs liability and regulation. Notably, we show that in a dynamic setting punitive damages do not eliminate the inefficient equilibrium, but make its attainment less likely; we thus provide a novel justification for punitive damages which is consistent with legal doctrine and practice. Our analysis illustrates the importance of compensating victims, when feasible, rather than merely burdening injurers, for efficiency purposes. This suggests that common theoretical conclusions on accuracy in assessing damages and on decoupling damages and compensation, which leave victims only partially compensated, may not apply.

Keywords: inadequate compensation of victims, alternative care, liability, accuracy, liability insurance, punitive damages

JEL classification: K13, K42.

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1. Introduction

Accidents can sometimes be avoided by either the “injurer” or the “victim”. For example, an accident involving a motorist and a pedestrian on a zebra crossing can be prevented by either the pedestrian crossing when the road is clear, or the motorist stopping and letting the pedestrian cross safely. Similarly, the harmful consequences of pollution can be avoided by relocating either the polluting factory or the nearby residents. In these and many other cases, which are commonly known in the literature as “alternative care” situations, conventional wisdom dictates that the costs of the accident should be borne by the party who could have prevented the accident at the lowest costs, that is, on the least-cost avoider (Calabresi, 1970; Landes and Posner, 1987). Arguably, letting the least cost avoider bear the cost of the accident induces her to take care and prevent the accident if and only if it is efficient to do so.

This conclusion is valid if the injurer, when he is the least cost avoider, bears the entire costs of the accident, and the victim is compensated for the harm done to her. Unfortunately, however, there are many situations in which, although the injurer is the least cost avoider, he does not bear the entire harm, and consequently the victim is not fully compensated. Typical examples are courts’ reluctance to award damages for standing-alone emotional harm caused by negligence, the low amount of damages awarded for non-pecuniary damages in general, and the partial or no compensation at all for victims when the injurer goes bankrupt. But more interestingly, there are other situations where the least cost avoider injurer bears the entire costs of the accident but the victim is not fully compensated, or even not compensated at all. The best example is wrongful death cases. Even if we assume that the injurer bears full liability for the harm done, the victim obviously cannot be compensated: all the damages go to her dependents and heirs. Another example is damages for severe bodily injuries: whatever the amount of damages is, most victims would not consider compensation as equivalent to their bodily integrity, both *ex post* or *ex ante*.

Conventional law and economics teaches us that, as long as the injurer bears liability for the entire harm, under-compensation or no compensation of victims is not a problem, and might even be a virtue in some cases. That leads leading scholars to suggest, for example, that decoupling liability and compensation, in the sense that the injurer bears full liability, but the damages go to the state (or any other third party), makes an economic sense (Polinsky and Che, 1991).

We argue that the conventional wisdom is wrong in this regard when it comes to alternative care cases. In these cases, when the injurer is the least cost avoider, his liability is not enough: compensation of the victim is a prerequisite for efficiency. The intuition of our argument is straightforward: in cases where the least cost avoider injurer is fully liable but the victim is not fully compensated, the injurer may opportunistically decide not to take care, relying on the incentives of the not-fully-compensated victim to take care and avoid her uncompensated harm. Similarly, the victim may decide not to take care, relying on the incentives of the injurer to take care and avoid liability. As a result, the injurer and the victim may both take care, may both refrain from taking care, or only one of them may take care.

To illustrate the problem, consider the following example, loosely reflecting the classical case *Beems*.¹ An injurer can prevent an accident resulting in the death of the victim by taking precautions that cost 20, and the victim can also prevent the accident by taking precautions that cost 40. In case of accident the injurer will be found liable and pay damages of 100 to the victim's dependents and heirs.

In this example, imposing on the injurer liability of 100 (or any liability higher than 20) should arguably induce him to take care and prevent the accident. If the injurer spends 20 to avoid the accident, the victim will have no incentive to take care, and efficiency is attained. However, since the accident results in the death of the victim, she cannot be compensated for her losses. Therefore, the victim has a strong incentive, even stronger than the injurer's incentive, to take care to avoid the accident, and the injurer is well aware of this. If the victim spends 40 to avoid the accident, the injurer has no incentive to take care, and inefficiency arises. In this example, it is not clear what the injurer and the victim would actually do, given the anticipated response of the other party, and it seems that any result could transpire: only the injurer takes care, only the victim takes care, both of them take care or none of them takes care. In *Beems* neither the injurer nor the victim exercised care, and the result unfortunately was the death of the victim.²

¹ *Beems v. Chicago, Rock Island & Peoria R.R.* 12 N.W. 222 (Iowa 1882).

² In *Beems* the victim, a brakeman, met his death in making an attempt to uncouple a tender from a car. When he went between the cars to uncouple them, the cars were moving at an improper and unusual rate of speed. The injurers, who were negligent in failing to obey a signal to check the speed of the cars, argued that the brakeman's action established contributory negligence. The courts stated that "[the brakeman] was authorized to believe that the motion of the car would be checked, and he was not required to wait, before acting, to discover whether obedience would be given to his signal. The jury could have found that after the signal had been given, and after he had gone between the cars, if their speed had been checked, he would not have been exposed to danger. His act, therefore, in going between the cars after having made the signal to check their

In the example, like in *Beems*, taking precautions was a discrete choice which would have prevented the accident altogether. But the inefficient equilibrium can arise even if taking precautions is a continuous variable, and even if there always remains a residual risk of an accident.

In this paper we rely on game theory and evolutionary game theory to rigorously analyze situations of alternative care where the injurer is the least cost avoider and the victim is not fully compensated for her losses and discuss possible solutions and policy implications. These situations give rise to two stable Nash equilibria in pure strategies, corresponding to situations in which one party always takes care while the other party never takes care, and one unstable mixed strategy equilibrium in which both parties take care with positive probability.³

The multiplicity of equilibria provides a powerful explanation for a puzzling phenomenon, according to which the same legal rules lead to different patterns of behavior in different countries. The example which opens the paper, of pedestrians being injured by motorists while crossings the street, demonstrates the puzzle: although the relevant liability rule is generally the same in US, Canada, Italy and Israel, namely, the injurer is held liable in case of an accident but the victim is not fully compensated, different patterns of interactions are observed between pedestrians and drivers in those countries. In particular, while in certain parts of the United States and Canada drivers usually stop at zebra stripes letting pedestrians cross the street safely, in both Italy and Israel pedestrians must be much more careful and make sure that the road is clear before crossing.⁴

From a policy perspective, the multiplicity of equilibria and the possibility of an inefficient equilibrium are disturbing and raise an important policy question: Can the legal system induce injurers and victims to “play” the efficient equilibrium? And if so how? The answer is yes. The legal system can play an important

speed, was not necessarily contributory negligence. . .”.

³These situations can be analyzed as an anti-coordination game, like the classical chicken or hawk-dove game, with two distinct populations, namely, injurers and victims (Schelling, 1960; Maynard Smith and Price, 1973; Maynard Smith, 1982).

⁴There is ample anecdotal evidence that the interaction between motorists and pedestrians at zebra crossings (and elsewhere) has a strategic dimension of the sort we discuss in this paper. See, (see, for example, Howarth, 1985). Indeed, citetschelling.60 has already pointed out that the chicken game can describe such an interaction. See also *The New York Times* on Aug 24th, 1993 “Pedestrian Crossing as Game of Chicken” (<http://tinyurl.com/brxav8w>) and on Jan 4th, 1998 “Why Pedestrian Play Chicken to Cross the Road (<http://tinyurl.com/bvah5cy>). In addition, there is plenty evidence that different pattern of behavior of motorists and pedestrians, sometimes refereed to as social norms, emerge in different places. See, for example, on the *Social Evolution Forum*, “Drivers versus Pedestrians: A case study of social norms” (<http://tinyurl.com/bufcuot>). Indeed, in certain places, tourists are urged not to play chicken with drivers.

role in securing the efficient outcome. The details, however, depend on whether compensation of victims is feasible or not. If it is feasible, full or adequate compensation for victims would eliminate the inefficient equilibrium and make the efficient equilibrium unique, because victims will have no incentive to take care, and therefore injurers will take care. To illustrate, in the example above, if the harm is such that the victim can be adequately compensated, specifically, if compensation is slightly above 60, she would have no incentive to take care (since her costs of care, 40, would be higher than her uncompensated loss). As a result, the injurer would take care and efficiency would be attained. Therefore, contrary to the common view in law and economics, compensation does matter for efficiency.

But more importantly, even if adequate compensation is not feasible, as in wrongful death cases, the legal system can offer several solutions to tackle the multiplicity problem. One solution is to revert to precaution costs liability. Under this rule, the injurer, if he did not take due care, is liable either for the harm, if the victim did not take care and the accident occurred, or for the costs of care incurred by the victim, if the victim took care and the accident was prevented. Precaution costs liability solves the multiple equilibria problem since the injurer's costs of care are lower than the victim's costs of care. However, it might not be practical, because it requires imposition of liability even when no accident and no harm occur. Another solution is to regulate the behavior of the injurer instead of imposing liability on the consequences of his behavior. Regulation solves the problem, because it induces the injurer to take care regardless of the behavior of the victim. Nevertheless, higher enforcement costs of regulation may render regulation socially undesirable in comparison to tort liability. Yet another solution is to change the nature of the interaction between injurers and victims from a simultaneous interaction to a sequential one with the victims moving first. Altering the nature of the interaction in this way solves the problem because the victim, anticipating that the injurer will take care, will not take care, and the injurer, observing that the victim does not take care, will take care. This solution may be largely impractical, as it is far from trivial to affect the nature of interaction between injurers and victims. However, there is an interesting example, namely, the use of Leading Pedestrian Interval, which gives pedestrians a head start in crossing the street on green light, while delaying for few seconds the green light given to motorists turning right or left, where this solution actually works.

Finally, the legal system can play a key role in promoting efficiency by affecting the dynamic interaction among injurers and victims. We show that higher damages

(as well as higher compensation) increase the *likelihood* of attaining the efficient equilibrium. To understand this novel result, consider an equilibrium resulting from a given level of liability and no compensation of victims, in which a fraction of the population of injurers take care (careful injurers) and a fraction of the population of victims take care (careful victims). If liability is now increased, more injurers will find it attractive to take care, and therefore the fraction of careful injurers will grow. As a result, more victims will find it attractive not to take care, and therefore the fraction of careful victims will shrink. As a result of the decline in the fraction of careful victims, more injurers will find it attractive to take care, and therefore the fraction of careful injurers in the population will grow further. This process continues until all injurers in the population are careful and all victims in the population are not. The higher the damages awards are, the more likely this process will transpire. It should be stressed that higher damages neither eliminate the inefficient equilibrium nor better compensate victims, since, by assumption, compensation is infeasible. Rather it is the effect of higher damages on the strategic interaction between injurers and victims which matters and makes the attainment of the efficient equilibrium more likely.

Our insights—(1) that in alternative care situations efficiency requires adequate compensation of the victim for the harm suffered, in contrast to merely burdening the injurer for the harm done, and (2) that even without adequate compensation higher damages increase the likelihood of attaining the efficient equilibrium—have important policy implications. The first insight provides a strong case for compensation of victims, either through the tort system itself or through insurance of the victims, and questions efficiency based solutions that involve under-compensation of victims. The second insight gives new economic rationale for punitive damages, and points out a severe inefficiency entailed by liability insurance when compensation is infeasible. We summarize all those policy implications below.

Compensation. The first implication is that compensation of the victim matters. Therefore, when it is possible, any means aimed at compensating the victim is effective in solving the multiple equilibria problem and in reaching an efficient equilibrium. In this regard, victims' insurance can play a role that goes beyond the usual function of spreading risk among risk averse parties. Because victims may lack incentives to buy insurance voluntarily, mandatory or public insurance may be justified in this case.

Accurate assessment of harm and decoupling of harm and damages. Courts sometimes rely on statistical evidence to assess harm and calculate damages. Re-

liance on average instead of actual harm in situations when the victim cannot be identified in advance is consistent with the view, shared by law and economics theorists, that for providing injurers with efficient incentives it is sufficient that their liability would be set at the level of expected harm (Kaplow, 1994; Kaplow and Shavell, 1996). We show that, in situations of alternative care awarding damages with reference to average harm based on observed accidents instead of actual harm may result in multiple equilibria of the kind described above. It follows that, in alternative care situations, insistence on accurate assessment of harm would be efficiency-justified. In a similar fashion, it is possible to question the conclusion that decoupling damages from harm improves efficiency by allowing to save on legal costs. As claimed by Polinsky and Che (1991), legal costs can be reduced by scaling down compensation to the victim (so that victims with high legal cost will not sue their injurers) while increasing at the same time damages paid by the injurer. Because with alternative care decoupling may determine a multiple equilibria situation in which an inefficient equilibrium is played, this conclusion needs to be qualified.

Punitive damages. Punitive damages are typically awarded only in serious injuries and wrongful death cases, but not in cases of property damages. Our argument explains why: in serious bodily injuries and in wrongful death cases victims are not fully compensated, or not compensated at all. Higher damages increase compensation in some cases of bodily injury, thereby eliminating the inefficient equilibrium (our first insight). But higher damages push the parties to the efficient equilibrium also in cases where higher damages do not affect compensation, as in wrongful death cases, as our second insight indicates. Thus, while the conventional economic rationale for punitive damages is the need for a damage multiplier to compensate for the risk that an injurer will escape liability, we show, that in alternative care cases, punitive damages push the injurer and victim to the efficient equilibrium and therefore justified even when the multiplier rationale does not apply. Given our novel rationale for punitive damages, in cases when compensation is not feasible the higher the punitive damages are, the higher the likelihood that the parties will reach the efficient equilibrium. Moreover, in contrast to other efficiency based rationales for punitive damages, such as the damages multiplier, our rationale is immune from Justice Stevens' criticism in *Cooper Industries v. Leatherman Tool Group, Inc.*, that "[h]owever attractive such an approach to punitive damages might be as an abstract policy matter, it is clear that juries do not normally engage in such a finely tuned exercise of deterrence calibration when

awarding punitive damages”. Indeed, under our analysis punitive damages need not be finely tuned: the higher they are, the higher the likelihood that the parties will reach the efficient equilibrium.

Liability insurance. In alternative care situation, when compensation is not feasible, liability insurance may operate as a commitment device not to take care in order to shift the costs of care to the victim, and therefore may result in an inefficient outcome. Indeed, if the injurer buys liability insurance, and if the insurance premium is not conditioned on behavior, he has no incentives to take care even if he is the least cost avoider, since he is under no risk of paying damages. The victim, being well aware of that, as well as that she would not be fully compensated, has incentives to take care and prevent the harm. The inefficient equilibrium in which victims take care results, while the injurer bears no cost as accidents are prevented and liability insurance premium is zero. This suggests that mandatory liability insurance, which has been recommended as a solution to the judgment proof problem (Shavell, 2005; Shavell, 2007), would be an insufficient solution for alternative care situations in which the victim cannot be fully compensated.

This paper builds on the long-standing tradition of analyzing alternative care situations, which goes back to the classical works of Coase (1960),⁵ Calabresi (1970),⁶ and Landes and Posner (1987).⁷ It is closely related to a recent paper by Dari-Mattiacci and Garoupa (2009), which demonstrates the inefficiencies that may arise in alternative care situations, where parties do not observe each other’s

⁵ In his classical paper “The problem of social costs”, Coase refers to many cases that illustrate alternative care situations. For example, when analyzing the case *Bryant v. Lefever* C.P.D. 172 (1878-1879) Coase states: “Who caused the smoke nuisance? The answer seems fairly clear. The smoke nuisance was caused both by the man who built the wall and by the man who lit the fires. Given the fires, there would have been no smoke nuisance without the wall; given the wall, there would have been no smoke nuisance without the fires. Eliminate the wall or the fires and the smoke nuisance would disappear”. Coase goes on to say with respect to the other cases he has analyzed: “Judges have to decide on legal liability but this should not confuse economists about the nature of the economic problem involved. In the case of the cattle and the crops, it is true that there would be no crop damage without the cattle. It is equally true that there would be no crop damage without the crops. The doctor’s work would not have been disturbed if the confectioner had not worked his machinery; but the machinery would have disturbed no one if the doctor had not set up his consulting room in that particular place. The matting was blackened by the fumes from the sulphate of ammonia manufacturer; but no damage would have occurred if the matting manufacturer had not chosen to hang out his matting in a particular place and to use a particular bleaching agent.”

⁶ A general theme in Calabresi’s analysis of nuisance and pollution is to whom to allocate the entitlement, that is to say the legal right to cause harm to the other party. The general answer is to allocate the right to the least cost avoider.

⁷ To the best of our knowledge, the term “alternative care”, in contrast to “joint care”, has been coined by Landes and Posner. Other papers that utilize a very similar, simple model are Chung (1993), Feldman and Frost (1998).

costs of care at the time of the accident and are unable to determine which party is the least-cost avoider and therefore fail to anticipate the outcome of the adjudication. As we demonstrate in this paper, inefficiencies may arise even if parties have perfect information and so the problems posed by Dari-Mattiacci and Garoupa are assumed away, as long as victims are not adequately compensated for their losses. In this regard, this paper should be viewed as complementing rather than substituting Dari-Mattiacci and Garoupa's contribution.

The paper is organized as follows. In section 2 we present a simple alternative care model and describe the equilibria resulting when compensation of the victim is inadequate. In section 3 we analyze possible solutions to the multiple equilibria problem depending on whether victims' compensation is feasible or not. In section 4 we reinterpret the model in a dynamic setting and illustrate how damages and compensation affect the likelihood that the system converges to one equilibrium or the other. In section 5 we consider the broader theoretical and policy implication of our analysis regarding the role of compensation in tort, accuracy in assessment of damages, decoupling of damages and compensation, a novel rationale for punitive damages, and the desirability of liability insurance. Section 6 concludes. Most of the proofs are relegated to the appendix.

2. Liability with inadequate compensation

We assume that the interaction (i.e. "game") between a potential injurer and a potential victim (henceforth "injurer" and "victim" respectively) will result in harm to the victim unless either the victim or the injurer takes care. Let the cost of care be x for the injurer and y for the victim, where $0 < x < y$. Let h be the harm resulting from the accident, where $h > y$.⁸ Under these circumstances, the injurer is the least-cost avoider and the socially efficient solution is for the injurer and only the injurer to take care. We assume that all the relevant parameters of the game are common knowledge, and that neither the injurer nor the victim is able to commit to an observable level of care and so they decide on their behavior independently and non-cooperatively. Thus, the interaction can be formalized as a simultaneous-move game with perfect information; accordingly, the solution concept is Nash equilibrium. We allow both players to play mixed strategies and analyze the equilibria of the game between the injurer and the victim.

⁸With $y > h$, the victim will never take care and the setting becomes equivalent to the standard unilateral care model.

We assume that in case of an accident, the injurer is liable for damages k which are arguably sufficient to induce him to take care, implying that $k > x$, while the victim receives only partial compensation $m < h$ for his losses. We further assume that $m < h - y$, and, for reasons that will become clear, we will refer to this assumption by saying that compensation is “inadequate”.

Partial compensation of victims can encompass a variety of situations. This includes the case in which the accident results in the death or serious injury of the victim. It can also reflect situations where “damages” are paid not to the victim but to a third party, like in the case of a sanction by a public enforcer conditioned on harm occurring (in the extreme case, we can assume $m = 0$). In addition, partial compensation occurs when courts systematically under-estimate the level of harm, or in situations in which injurers have insufficient assets to cover all harm (in these cases $m = k < h$).

The normal form game, which we will sometime refer to as the “Inadequate Compensation Game”, is

		Injurer	
		Care	No Care
Victim	Care	$-x, -y$	$-x, 0$
	No Care	$0, -y$	$-h + m, -k$

Since $x < k$ and $y < h - m$, we have an *asymmetric anti-coordination game*. This game has three Nash Equilibria: two pure and one mixed strategy equilibrium. We indicate these equilibria by the probability pair (p, q) , where p and q reflect the probability that the injurer and the victim respectively take care.

NE1: $(p, q) = (1, 0)$, the efficient pure strategy equilibrium in which the injurer always takes care and the victim never takes care, there are no accidents and the social cost is accordingly x .

NE2: $(p, q) = (0, 1)$, the inefficient pure strategy equilibrium in which the victim always takes care and the injurer never takes care, there are no accidents and the social cost is $y (> x)$.

NE3: $(p, q) = \left(\frac{h-m-y}{h-m}, \frac{k-x}{k}\right)$, the mixed strategy equilibrium in which both parties take care with positive probabilities and there is a positive probability

of accident, so that the social costs are $x + y - \frac{xy(k-m)}{k(h-m)}$.⁹

Since social costs in the mixed strategy equilibrium are larger than y ,¹⁰ the three Nash equilibria can be ranked according to their social desirability, with NE1 the best and NE3 the worst Nash equilibrium.

As pointed out in the introduction, the multiplicity of equilibria can explain a puzzling phenomenon; how the same legal rules lead to different patterns of behavior in different places.¹¹ At the same time, it suggests that the effects of the legal rules on outcomes may be unpredictable; that is, we cannot say which of the different Nash equilibria, if any of them at all, will be played by the injurer and the victim. This also creates a problem in making normative comparisons.¹² More importantly, the multiplicity of equilibria means that inefficiency may arise. We shall call this the “multiplicity problem”. The normative issue is, therefore, if and how the legal system can solve this problem. In particular, how the legal system can induce parties to coordinate on the efficient outcome. In the next section, we shall explore possible solutions to the multiplicity problem.

But before doing so let us note that although our setting may seem restrictive, it is much more general and robust. In our setting, there is no harm if the injurer takes care, and therefore there is no difference between strict liability or negligence based rule. In the appendix we show how our results extend to situations in which care reduces but does not eliminate the probability of harm; although in this case there is a difference between strict liability and negligence, our main results carry over straightforwardly. In addition, we chose to simplify the analysis by assuming that precautions are binary (either a party takes care or does not take care). But,

⁹Checking that the two pure strategy equilibria are in fact equilibria is trivial. The mixed strategy equilibrium can be derived using the indifference condition. In particular, if the injurer takes care with probability p , the victim is indifferent between taking and not taking care if $x = (1 - p)k$. Similarly, if the victim takes care with probability q , the injurer is indifferent between taking and not taking care if $y = (1 - p)(h - m)$. By solving these two equations we obtain the mixed strategy equilibrium.

¹⁰In particular, $y < h - m$ and $m \geq 0$ imply that $y(k - m) < k(h - m)$ for all k .

¹¹In addition to the example in the Introduction, regarding the interaction between drivers and pedestrians, the multiplicity problem can explain why under the same legal rules one can find polluted rivers that no individual swims in, and at the same time, clean rivers that individuals do use for swimming.

¹²For example, the analysis seems to imply that a rule of no liability, which uniquely implements NE2, may or may not be socially preferable to strict liability or negligence. The reason is that under strict liability or negligence there are three Nash equilibria: one identical (NE2), one inferior (NE3), and one superior (NE1) to the unique Nash equilibrium under the no liability rule (NE2). However, as we do not know the likelihood of playing the different Nash equilibria under strict liability or negligence, we cannot make further comparisons between the social desirability of the different rules.

as we illustrate in the Appendix, our main results, including the existence of multiple equilibria, may arise in more general settings in which the choices of care by the parties are continuous variables.

3. Possible solutions

To solve the multiplicity problem identified in this paper it is useful to distinguish between two cases: (1) when compensation of the victim is feasible in principle and (2) when it is not. The latter reflects, for example, instances when the accident results in serious bodily injuries or death of the victim. As we will show the set of solutions to the multiplicity problem may be different in these two cases; indeed, since the multiplicity problem stems from the fact that neither the injurer nor the victim has a dominant strategy to take or to refrain from taking care, in the former case solutions will deal with the victim, while in the latter they will generally but not exclusively deal with the injurer.

3.1. Feasible Compensation

The multiplicity of equilibria in the Inadequate Compensation Game arises because victims are not sufficiently compensated for their losses in case of an accident, and as a consequence, they do not have a dominant strategy to refrain from taking care. Therefore a trivial solution is to compensate victims, when this is feasible. To illustrate, consider again the Inadequate Compensation Game and suppose that compensation were at a level $m \geq h - y$. Then even if the injurer did not take care, the victim would not take care because $y \geq h - m$. Therefore, with adequate compensation, the victim has a dominant strategy not to take care. As a result, the injurer who does not have a dominant strategy himself will take care and efficiency is uniquely attained.

Victims' compensation can be achieved in different ways. Although a straightforward solution is to compensate victims through the tort system, this is by no means the only possibility. Any other form of compensation will do the job. If, for example, victims know they will be fully compensated through the insurance system, they will not take care whatever the choice of the injurer; the injurer will anticipate victims' behavior and find it optimal to take care, so that the efficient equilibrium will result. In addition, in equilibrium, because the injurer will take care, the insurance premium should and would be zero.¹³ Indeed, in our setting

¹³There will be no incentives on the part of the victim and the insurance firm to condition

the role of insurance goes beyond the standard benefits from risk pooling among risk averse individuals. However, it cannot be taken for granted that victims or injurers will have sufficient incentives to buy insurance voluntarily. Lack of incentives may discourage both injurers and victims from buying proper insurance coverage.¹⁴ Mandatory insurance or publicly provided social insurance may be required in this case.¹⁵

3.2. *Unfeasible Compensation*

Compensating victims for their losses is a straightforward way to attain efficiency in alternative care situations, but it is not always feasible. When victims' compensation is infeasible, solutions to the multiplicity problem should be generally aimed at the injurer. In particular, incentives should be structured so that the injurer would have a dominant strategy to take care. We shall discuss in this part the role played by precaution costs liability and regulation. As we shall point out, these possible solutions may suffer from some drawbacks and may not always be practical. We shall also discuss the possibility to alter the nature of the interaction between injurers and victims from a simultaneous to a sequential interaction.

Precaution-cost liability. At least in theory, an efficient outcome can be induced by adopting a precaution-cost negligence liability rule.¹⁶ Under such a rule, the injurer who fails to take due care is liable either for the harm, if the victim did not take care and the accident occurred, or for the costs of care incurred by the victim, if the victim took care and the accident was prevented. Assume that the victim is

coverage or the premium on the behavior of the victim. Indeed, the incentives of both parties would be to make sure that the victim does not take care, so that the injurer will take care.

¹⁴ As to injurers, it is clear that if injurers are risk neutral they would have not incentive to buy liability insurance. With regard to victims' incentive to buy insurance, a relevant aspect is whether the injurer, when he takes his decision, knows (can observe) whether the potential victim is insured or not. If the injurer knows that the potential victim is insured, so that he conditions his choices on this observation, it is in the interest of the victim to buy insurance; by purchasing insurance the victim signals that she will not take care, so that the injurer is induced to take care. If instead the interaction is anonymous, in the sense that an injurer does not observe whether a specific potential victim is insured, the individual decision of the potential victim does not affect the injurer's behavior (which depends on whether a large enough share of victims is insured or not) and she may lack any incentive to buy insurance. Due to administrative costs, this will be certainly the case under our assumption that care reduces the risk of an accident to zero, as there is no point in paying a positive insurance premium when no accident takes place (things may be different in cases in which there is a residual probability of being harmed, hence there is an incentive for victims to buy insurance, even when care is taken).

¹⁵ The case for mandatory liability insurance is further considered below in section 5.5.

¹⁶ This possibility is extensively discussed, among other, by Wittman (1981) and Rose-Ackerman (1989)

not compensated for the harm if an accident occurs (since she dies, for example), but she can be compensated for her costs of care. Under these assumptions, the normal form game becomes:

		Injurer	
		Care	No Care
Victim	Care	$-y, -x$	$0, -y$
	No Care	$0, -x$	$-(h - m), -k$

Because the injurer has a dominant strategy to take care regardless of what the victim does (since $x < k$ and $x < y$), the game has a unique Nash equilibrium in which the injurer takes care and the victim, who does not have a dominant strategy herself, does not take care.

Precaution-costs liability can be regarded as an extension of the doctrine of “mitigation of losses” in sequential torts to simultaneous torts. Under such doctrine, a victim has a duty to mitigate her losses resulting from the behavior of a negligent injurer. But the negligent injurer is liable both for the harm suffered by the victim and the (optimal) costs of care taken by her.

While precaution-costs liability theoretically solves the multiplicity problem, it seems impractical in many real cases, since it requires that courts will adjudicate cases and impose liability on the injurer for the victim’s costs of care even if no accident has occurred.¹⁷ This is not the usual way courts operate, and therefore it may not be feasible.¹⁸ Moreover, precaution costs liability requires a negligence based liability system. Under strict liability, holding the injurer liable to the precaution costs taken by the victim, in addition or as a substitute to harm, cannot solve the problem, because if the victim takes care, the injurer has no incentive to take care, since taking care does not release him from liability.

Regulation of injurers’ behavior. Another possible solution to the problem at hand is to regulate the behavior of the injurer instead of imposing liability on the

¹⁷ If care does not eliminate harm but only reduces the probability of an accident, precaution-cost liability can be imposed whenever an accident occurs. However, to lead to the efficient outcome liability in this case should be inflated by the probability of an accident. Again, by doing so, the injurer will have a dominant strategy to take care, and as a result the victim will not take care.

¹⁸ For example, as Dari-Mattiacci and Garoupa (2009, p. 255) point out, “[h]ow can courts verify whether the fact that a motorist slowed down before a crossing point really avoided an accident that would have otherwise occurred? How can they possibly quantify the costs of care? For this reason, precaution cost liability, might not be always a practical solution.”

consequences of his behavior. In the present setting, this means, for example, that the injurer should pay a fine to the regulator if he does not take care, regardless of whether an accident occurred or not. Assuming for simplicity that the victim is not compensated at all for her losses, the game between the injurer and the victim becomes:

		Injurer	
		Care	No Care
Victim	Care	$-y, -x$	$-y, -s$
	No Care	$0, -x$	$-h, -s$

If the (expected) fine s is set at a level higher than the costs of care ($s > x$), the injurer will have a dominant strategy to take care and, as a result, the victim, who does not have a dominant strategy herself, will not take care (since $y > 0$). The unique Nash equilibrium of this game is the efficient equilibrium.¹⁹

However, regulation might be itself costly to enforce, for example because it is extremely difficult to detect injurers' behavior in all cases in which it is potentially harmful. To take a concrete example, accidents between motorists and pedestrians on a zebra crossing can be controlled by regulating and, more importantly, enforcing the behavior of motorists. However, it is probably very costly to deploy police personnel in zebra crossings to enforce the behavior of motorists ex-ante, rather than impose liability on motorists ex-post when accidents occur. For regulation to be socially superior to liability, it must be the case that enforcement costs are not too high.

Regulating the nature of interaction. Another possible solution to the multiplicity problem is to regulate the nature of the interaction between injurers and victims, changing it from a simultaneous move game to a sequential move game in which the victim moves first. If the game can be transformed in this way, the multiplicity problem will disappear, because the victim will have an incentive not to take care, anticipating that the injurer will respond by taking care, and the

¹⁹ One may imagine that it is possible to solve the multiplicity problem by regulating the behavior of the victim. For example, if the victim could be directed not to take care, the multiplicity problem would be solved, because the injurer would take care. However, it is probably impossible to regulate the behavior of the victim in the traditional "command and control" way, that is, by threatening the victim with a fine should she take care. The reason is that, unless the victim expects that the injurer will take care, she will probably prefer to take care and incur the fine, instead of suffering harm. This would obviously be the case if the accident results in the death of the victim.

injurer will indeed respond in the anticipated way, and efficiency will be uniquely attained. This solution may appear largely impractical, because it is far from trivial that a policy maker can affect the nature of interaction between injurers and victims.

However, there is an interesting example, demonstrating that such a solution is not impossible. Accidents involving motorists and pedestrians of the sort we analyze in this paper occur not only on zebra crossing, but also when motorists turn right or left on a green light and pedestrian cross the street on a crosswalk on a green light as well. To deal with this dangerous situation, an ingenious, yet simple measure has been devised: Leading Pedestrian Interval (LPI). The LPI provides a few seconds head start to the pedestrians. The pedestrian green signal comes on while the signal for the drivers remains red; after pedestrians have had a chance to start their crossing, usually three to five seconds, the drivers get their green signal. In effect, the LPI measure transforms the interaction between motorists and pedestrians from a simultaneous to a sequential move game in which the pedestrians are the first movers. There is a growing evidence that the LPI measure changes the pattern of behavior between motorists and pedestrians and also reduces substantially the rate of accidents (see, for example Fayish and Gross, 2010).²⁰ As a result, there has been a growing use of LPI in different cities across the United States, including New York City and Chicago, as well as in other parts of the world.²¹

4. The role of damages (and compensation) in a dynamic analysis

In the previous part we analyzed different solutions to the multiplicity problem, but we did not discuss the role damages might play in securing the efficient outcome. We shall take this task in this part.

Interestingly, in the Inadequate Compensation Game the level of damages k affects neither the strategies nor the social costs in the pure strategy equilibria NE1 and NE2. In particular, since there is no accident if either the injurer or the

²⁰ Consider also the following quote from *Status Report*, the newsletter of the Insurance Institute for Highway Safety (Aug 30, 1997 issue, Vol. 32, No. 7): “After leading pedestrian interval signals were installed, conflicts were nearly nonexistent. The odds of a conflict for pedestrians leaving the curb during the beginning of the walk period were reduced by about 95 percent, from 2.8 to 0.2 per 100 pedestrians. The likelihood of a pedestrian yielding to a turning vehicle decreased by about 60 percent.”

²¹ In Chicago, see the Chicago Pedestrian Plan at p. 26. <http://chicagopedestrianplan.org/pedestrian-plan/>. For a list of places in New York City, where LPI are deployed see <http://www.nyc.gov/html/dot/html/signs/leading-ped-intervals.shtml>.

victim take care, no liability will actually be imposed.

As to NE3, it is evident from $(p, q) = \left(\frac{h-m-y}{h-m}, \frac{k-x}{k}\right)$ that damages do not affect the mixed strategy equilibrium of the injurer (i.e. the probability that the injurer takes care remains unchanged), although they change the equilibrium mixed strategy of the victim. Quite paradoxically, higher (lower) damages imply that at NE3 the probability that the victim takes care is higher (lower);²² similarly, a change in compensation m does not affect the mixed strategy equilibrium of victim, although it changes the equilibrium mixed strategy of the injurer.²³

Therefore, it seems that damages has no role to play in securing the efficient equilibrium.²⁴ However, as we shall now argue, damages have an important role in making the efficient equilibrium, the more likely equilibrium to occur.

4.1. *Dynamic Analysis*

With multiple equilibria, the solution concept of Nash equilibrium does not provide a satisfactory prediction as to how the “game” is going to be played. The concept of Nash equilibrium itself is a static rather than a dynamic concept; this means that it does not deal with the question of how the equilibrium (or different equilibria) arise in the first place or what would happen if the equilibrium will be violated. Moreover, the Nash Equilibrium concept says nothing on the question which equilibrium is more likely to occur.

To answer these questions, narrow the set of possible equilibria, and discuss the role of damages, we need to analyze the Inadequate Compensation Game in a dynamic settings. To this purpose, we assume that we have a large population of individuals from which two players are randomly drawn and assigned the roles

²² It needs to be clarified that we are referring here to the probabilities at the mixed equilibrium. This does not contradict what we said in the example in the introduction; namely that in a dynamic system, starting from a mixed strategy equilibrium, an increase in the level of damages pushes the parties towards the efficient equilibrium. On this point, which involves the issue of stability of the mixed strategy equilibrium, see the dynamic analysis below.

²³ Moreover, the social costs in the mixed strategy equilibrium NE3 are decreasing in k as long as $m > 0$ (otherwise social costs in the mixed strategy equilibrium are also unaffected by k): formally, let σ be the social costs of the mixed strategy equilibrium. Then $d\sigma/dk = -xym/[k^2(h-m)] < 0$. Because $\lim_{k \rightarrow \infty} \sigma = x + y - xy/(h-m) < x$, we can conclude that NE3 is always the worst equilibrium from a social perspective.

²⁴ An exception applies if the applicable rule is negligence and care does not eliminate the possibility of an accident. In this case, damages at a sufficiently high level may secure the efficient equilibrium by making care the dominant strategy of the injurer. To illustrate, suppose that if the injurer or the victim take care there is still a residual risk of an accident ϵ . Under a negligence rule an injurer who takes care is not liable for damages, while an injurer who did not take care is liable for damages. Therefore, if damages k are set such that $k \geq x/\epsilon$ the injurer would have a dominant strategy to take care.

of injurer and victim and who can condition their strategy on the role they have been assigned to.²⁵ In such a framework, a mixed strategy equilibrium can be interpreted as a situation in which a fraction p of injurers and a fraction q of victims (or those who have been assigned to these roles) are careful (i.e., take care) while the remaining fractions are non-careful (i.e., do not take care). We can introduce learning in this picture by assuming that a fraction of individuals compare their payoff to the payoff of the other individuals in the same role, and adjust their behavior if a strategy gives a higher payoff than the other strategy. This results in a replicator dynamics (Taylor and Jonker, 1978) in which a fraction of careful injurers p changes at a rate equal to the difference between the payoff of the careful injurer and the average payoff in the population of injurers; a similar assumption is made for the fraction of careful victims q .²⁶ The dynamic system is specified and discussed in the Appendix, where we show that *the pure Nash equilibria NE1 and NE2 of the Inadequate Compensation Game are asymptotically stable²⁷ fixed point of the system, while the mixed strategy equilibrium NE3 is unstable.*

To understand this result, consider that a fraction p in the population of injurers take care (i.e., careful injurers) and a fraction q in the population of victims take care (i.e., careful victims). While a careful injurer always gets $-x$, the average payoff in the population of injurers is $-px - (1-p)(1-q)k$; hence, the population of careful injurers will grow (shrink) as $x < (>)px + (1-p)(1-q)k$, i.e. as q is lower (higher) than $(k-x)/k$. Similarly, because a careful victim always gets $-y$ and the average payoff in the population of victims is $-qy - (1-q)(1-p)(h-m)$, the proportion q of victims who take care increases (decreases) as $p < (>)(h-m-y)/(h-m)$, i.e., as p is lower (higher) than $\frac{h-m-y}{h-m}$. In other words, a low level of q induces

²⁵ Alternatively, we can think of two populations of individuals (injurers and victims) whose members meet at random and play the Partial Compensation Game. This interpretation of the game fits well with many real life cases, such as the interaction between motorists and pedestrians, or between polluting firms and residents.

²⁶ An alternative approach to stability is based on the concept of Evolutionary Stable Strategies, which is related to the biological concept of species, and to the idea that a strategy—corresponding to a species—is evolutionary stable if a whole population using such strategy cannot be invaded by a small group of mutants adopting a different strategy. The analysis of the evolutionary stability of the liability game is made easy by the fact that such game is equivalent to an asymmetric hawk-dove game with role play (Maynard Smith and Price, 1973; Maynard Smith, 1982). It can be shown that in our game the strategies corresponding to the two pure strategy Nash equilibria are evolutionary stable, while the mixed strategies in NE3 are not; i.e. a small “mutant” subgroup playing either the strategies in NE1 or the strategies in NE2 could invade a population playing the mixed strategies in NE3.

²⁷ An equilibrium of a dynamical system is asymptotically stable if starting sufficiently close to the equilibrium point the system eventually converges to it. Formally, \hat{z} is an asymptotically stable equilibrium if there exists $\delta > 0$ such that, for all $\|z(t) - \hat{z}\| < \delta$, it is $\lim_{t \rightarrow \infty} z(t) = \hat{z}$.

more injurers to take care (a higher p), and a lower level of p induces more victims to take care (a higher q).

Now, when $q = (k-x)/k$ and $p = (h-m-y)/(h-m)$ —i.e. at the mixed strategy equilibrium—there is no motion in either p or q . However, a small perturbation of p or q with respect to the equilibrium values will make the dynamic system move away from NE3, along a trajectory which converges asymptotically to either one of the stable pure strategy equilibria.

Because NE3 is not stable, we can rule it out as an equilibrium description of how the game will be eventually played in the population. However, NE3 is still very important: it is a saddle point for the dynamic system, and it lies on the saddle path separating the basins of attraction of the two stable Nash equilibria NE1 and NE2, i.e. the set of initial values (p, q) that make the system converge asymptotically to one equilibrium or the other. It is possible to illustrate the dynamics of the system through the phase diagram in figure 1; the diagram shows the saddle path passing through NE3. The area below such path represents the basin of attraction of the efficient equilibrium NE1, while the area above it is the basin of attraction of NE2.

As we noted above, the mixed strategy equilibrium played by the victim increases with the level of damages, while the mixed strategy equilibrium played by the injurer decreases when the level of compensation increases; hence, when starting at NE3, either change makes the system converge to NE1. Starting at NE3, if damages k increase the injurer reacts by increasing the probability of taking care (i.e. the fraction of careful injurers increases), and the victim responds by decreasing the probability of taking care (i.e. the fraction of careful victims decreases). This leads the injurer to further increase the probability of taking care and so on. This process continues until the injurer always takes care (i.e. all injurers are careful) and the victim never takes care (i.e. all victims are non-careful). A similar explanation applies to an increase in m . From this, it is a short step to conclude that *the basin of attraction of the efficient equilibrium NE1 is made larger by an increase in damages k or (with $m < h - x$) by an increase in compensation m* (see Appendix for a formal proof).

Figure 2 illustrates the effect of an increase in k and m on the saddle path and on the basin of attraction of the efficient equilibrium.

The fact that the basin of attraction of the efficient equilibrium increases with damages and compensation does not imply that, once an inefficient equilibrium such as NE2 is reached, it is possible to escape from it simply by increasing the level

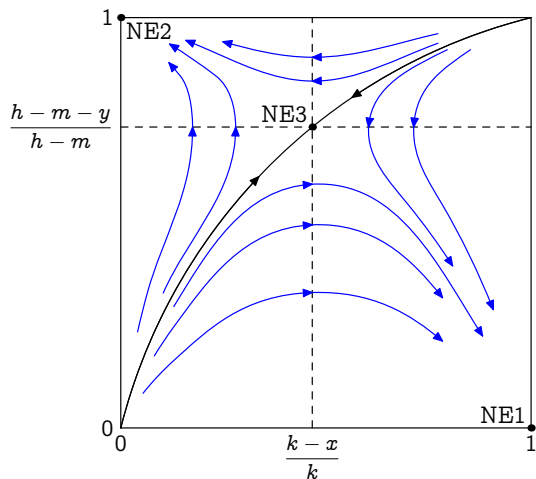


Figure 1. Phase diagram

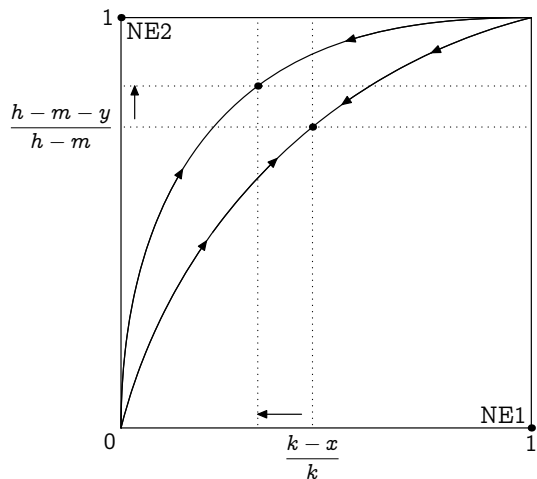


Figure 2. Effect of a higher k and m on the basins of attraction of stable equilibria

of damages and/or compensation (except when m is increased so that $m \geq h - x$). However, it suggests that higher damages or compensation can make NE1 more likely than NE2 when individuals in the population are not playing equilibrium strategies. This might be the case when new rules are established (e.g. there is an institutional shock of some kind), or when such rules have not been learned by a share of the population (e.g. because there is immigration or other changes in the population).

Our dynamical analysis suggests that damages and compensation can play an important role in *mitigating* the inefficiency resulting in the Inadequate Compensation Gaem, by making the efficient equilibrium more likely to occur. We shall discuss below the policy implications of this analysis to punitive damages and harm-based regulatory sanctions in excess of social harm.

5. Policy and theoretical implications

In the previous sections we have demonstrated how alternative care with inadequate compensation can result in multiple equilibria and offered solutions to this problem. In this section we shall discuss the broader theoretical and policy implications of our analysis. In particular, we will discuss the puzzle in law and economics concerning the role of compensation in tort law, and the policy implications of our analysis regarding the desirability of accuracy in the assessment of damages and the efficiency of decoupling damages and compensation. In addition, based on the dynamic analysis of section 4, we will offer a novel justification for punitive damages and demonstrate its consistency with legal doctrine and prac-

tice. Finally, we will examine the role of liability insurance in situations when victims' compensation is and is not feasible.

5.1. *Compensation*

As we argue in this paper, in alternative care situations, it is necessary, when possible, to compensate the victim for her losses in order to secure efficiency. This argument partially solves a “puzzle” in law and economics regarding the important role of compensation in tort law. As is well known, the great majority of legal scholars, lawyers, judges, and probably laypersons, appear to view compensation as a primary purpose of accident liability. On the other hand, compensation in the two widely held paradigms of accidents, namely, unilateral accident and bilateral accident models, is considered either unnecessary or harmful for efficiency purposes. In the *unilateral accident model*, the victim is assumed to be passive and to lack the ability or opportunity to affect the expected harm. Therefore compensation of the victim is neither necessary nor harmful to induce efficient behavior and attain the first best outcome.²⁸ In the *bilateral accident model*, it is assumed that both the injurer and the victim can affect the expected harm and, unlike the alternative care situations, it is efficient for both the injurer and the victim to take care. The common wisdom is that in this case actual compensation of the victim (as secured, for example, by strict liability) is an obstacle to achieving the efficient outcome. The reason is that if the victim is always compensated, she lacks any incentive to take care. Indeed, in bilateral accident models simple negligence achieves the efficient outcome because it creates double liability in the margin. Alternatively, imposing strict liability on the injurer without compensating the victim is also considered a method for obtaining the efficient solution. The analysis in this paper partially mitigates the different views about the role of compensation in tort law by providing an efficiency based justification for compensation. It also demonstrates that the alternative care situations should stand as an independent paradigm with respect to unilateral and bilateral care, deserving specific attention both from a theoretical and from a policy point of

²⁸ A qualification is that compensation of the victim is necessary for bringing suit against the injurer. But this of course is not a problem in our model as long as victims are at least partially compensated (see also the discussion in Polinsky and Che, 1991). Moreover, incentives to bring suit can be attained in other ways. Furthermore, in our setting there is no real problem of incentives to bring suit, because usually there is a party that recovers damages. For example, if the accident results in the death of the victim, then the estate or heirs of the victim will have incentive to bring suit.

view.

But more importantly, our argument that compensating victims for their losses is an important feature of an efficient tort system sheds new light on policy proposals based on under-compensation; in particular, as discussed below, our analysis brings new insights on accuracy in the assessment of damages and on the desirability of decoupling damages and compensation.

5.2. Accuracy in the assessment of damages

It is debated whether there is a social justification for an accurate measurement of actual harm, or whether efficiency can be attained more cheaply by relying on estimates of harm based on statistical information. For example, Kaplow and Shavell (1996) conclude that “accuracy in assessment of harm cannot influence the behavior of injurers—and is therefore of no social value—to the degree that they lack knowledge of the harm they might cause when deciding on their precautions” (see also Kaplow, 1994). This is usually taken to imply that, from the point of view of incentives to injurers, setting damages equal to average harm is as effective as using more accurate measures of actual harm on a case by case basis. As a consequence, the argument goes, courts should rely on general averages and statistical evidence rather than spending resources in improving the precision of assessment of damages for each single case. Courts, however, do not usually follow this policy suggestion and allow parties to bring evidence as to the level of harm. In particular, courts usually attempt to estimate uncertain components that are not too speculative when losses are associated with harm to property or forgone profits. On the other hand, when it comes to physical injuries and death, courts in many countries estimate diminution in earning capacity and in future medical expenses as best they can, often using actuarial and statistical data (Shavell, 2004, p. 241).

Contrary to the standard setting in which the role of victims is not explicitly considered, the fact that with damages based on average harm some victims are under-compensated may be crucial in the alternative care setting.²⁹ Namely, under-compensation of some victims creates the possibility of multiple equilibria. This multiplicity problem can arise if damages are set equal to the average harm

²⁹In situations of unilateral accidents awarding average damages is irrelevant, since victims cannot affect harm. On the other hand, in bilateral accident model, with independent care, a rule of negligence induces efficient outcome, because the injurer abide by the due care standard and the victims therefore take care.

actually incurred by victims in equilibrium.

To illustrate this consider the following example. Suppose half of victims suffer a high loss of 200 and half of them suffer a low loss of 100 if an accident occurs. Suppose further that victims know the potential loss they will suffer (i.e., their type) but injurers do not know it ex-ante. Suppose finally that the injurer is the least cost avoider with respect to both type of victims.

The average harm actually observed is 150 if no one takes care, while it is 100 if only high loss victims take care (because only low loss victims will be involved in accidents) and 200 if only low loss victims take care (because only high loss victims will be involved in accidents). In addition, if injurers take care and no victim takes care, the average harm is presumably 150.³⁰

Suppose that the cost of care for the injurer is 60 and for the victims of both types is 80. If victims do not take care, the injurer will take care because his costs of care 60 is less than the liability costs, which are in this case 150. At the same time, if the injurer takes care, victims will not take care, because there is no accident: efficiency is attained. However, there is also an inefficient equilibrium. Consider that the injurer does not take care, low loss victims do not take care, but high loss victims take care. Since high loss victims take care and low loss victims do not take care, average harm based on the observed distribution of accidents in equilibrium is 100. Therefore, an injurer who does not take care faces expected liability of 50 (0.5×100), which is less than his costs of care 60. Therefore, the injurer prefers not to take care. At the same time, if the injurer does not take care, while high loss victims take care, then the net loss for a high loss victim who will not take care is 100 ($200 - 100$), which is higher than her costs of care 80. As a result, high loss victims would find it in their interest to take care, and inefficiency arises.³¹

This example is easily generalizable (see the Appendix), and it shows that the standard claim that courts can induce efficient care relying on statistical evidence of average harm needs, at a minimum, to be qualified. Individuals can be trapped in a situation where high loss victims are under-compensated, and care is taken by the highest cost avoider. Interestingly, for this to happen it is crucial that damages

³⁰ For this to be unambiguously true, one needs to assume that there is a residual probability of an accident even if parties take care, for example because of “mistakes” by injurer. In our formal model in the appendix, we assume that care either by the injurer or the victim reduces the probability of an accident but does not eliminate it completely.

³¹ Low loss victims are fully compensated for their losses, so they do not have an incentive to take care.

are set equal to the average harm actually incurred by victims *in equilibrium*. Indeed, as we prove in the Appendix, the multiplicity problem cannot occur if damages are set equal to the average harm calculated with respect to the entire population of victims.³²

Hence, at least in principle, reliance on the underlying distribution of harm among potential victims could solve the problem and vindicate the use of average harm; however, this would require that the effects of out of equilibrium behavior is considered, and it is doubtful that courts have all required information. Although no clear distinction is usually made when this issue is discussed in the literature as to which notion of average harm is relevant, the reference to the actual distribution of harm observed in equilibrium seems more consistent with the idea of using statistical evidence; moreover, taking the average across actual harm suffered by victims effectively minimizes the error. All things considered, accurate assessment of harm might lead to a safer solution to secure proper incentives to injurers.

5.3. *Decoupling and legal costs*

In our analysis we have made the simplifying assumption that liability involves no legal costs. Among the implications of taking legal costs into account is the claim that it might be efficient to decouple damages paid by injurers from compensation received by victims. The argument, developed by Polinsky and Che (1991), parallels the well known result by Becker (1968) that, whenever it is possible, it is efficient to reduce the probability of a sanction and increase its magnitude. In the case of litigation, this outcome is obtained by reducing the compensation to the victims, hence victims' incentive to take costly legal action against the injurer, and by increasing at the same time the damages paid by the injurer; this results in decoupling, with expected damages equal to harm and expected compensation less than harm.

In alternative care situations, decoupling of damages and compensation may lead to multiple equilibria.³³ To illustrate consider the following example. Suppose that care by either the injurer or the victim reduces the chances of an accident

³²This is clear also in the example above, as the average harm with respect to all potential victims is always equal to 150.

³³In the literature there are other possible justifications for decoupling, which we do not consider in this paper, and for which our claim should be verified on a case by case basis. Let us also note that the analysis in this paper, in which the injurer pays for damages but the victim is not compensated at all, can be viewed as an extreme form of decoupling. A different criticism of Polinsky and Che's conclusion is provided by Garoupa and Sanchirico (2010).

from certainty to 20%.³⁴ Suppose further that the cost of care is 60 for the injurer and 80 for the victim, and harm in case of an accident is 200, so that the expected benefit from taking care is 160 (0.8×200) and it is efficient that injurers take care. Suppose, finally, that half of the victims incur a legal cost of 50 if they decide to bring suit after an accident has occurred, while the remaining victims and injurers incur no legal costs. With full compensation of victims injurers will take care and victims will bring suit when an accident occurs, so that the social cost is 105 ($60 + 0.2 \times 200 + 0.2 \times 0.5 \times 50$).

As Polinsky and Che argue, social cost can be reduced by decoupling liability and compensation. In our example, it is desirable to limit compensation to 50, so that high legal cost victims never bring suit, while at the same time liability is increased to 400, so that in case of accident (with only low legal costs victims bringing suit) the expected damages for the injurer remains equal to social harm.

If victims do not take care, the injurer will take care because in this case his expected costs will be 100 ($60 + 0.2 \times 0.5 \times 400$), which are lower than his expected costs if he does not take care, which are equal to 200 (0.5×400). At the same time, if the injurer takes care, victims will have no incentive to take care. In such equilibrium, in which only low costs victims bring suit, the social costs will be 100 ($60 + 0.2 \times 200$), which are less than the social costs when damages are equal to harm due to savings in legal costs of high legal costs victims (the savings are equal to $5 = 0.2 \times 0.5 \times 50$).

However, there is another possible equilibrium.³⁵ Consider the case that injurers do not take care. Victims with a high legal cost will find it optimal to take care; while they do not rely on liability because the legal cost is higher than damages, by taking care they can reduce their cost from 200 to 120 ($80 + 0.2 \times 200$). As to victims with zero legal cost, they will also find it in their interest to take care. This is so because when an accident occurs they receive compensation of 50, so their expected net harm is 150. Therefore, the expected cost when they do take care is 110 ($80 + 0.2 \times 150$), which is lower than the cost when they do not take care (150).³⁶ Clearly, if all victims take care, there is no point for the injurer

³⁴To account for litigation costs we must assume that care does not prevent the accident altogether. Otherwise, if the injurer takes care litigation costs are never incurred, and so the problem is assumed away.

³⁵Observe that without decoupling (i.e. with full compensation) the victim will never find it in her interest to take care as long as her costs of care is higher than the reduction (because of care taking) in her expected legal cost.

³⁶This suggests that a necessary condition for victims to take care is that their cost of care is lower than the expected reduction in uncompensated harm. In our example, uncompensated harm

to take care, *whatever the level of damages*. The social costs associated with this equilibrium are 120 ($80 + 0.2 \times 200$). Therefore, the game has an additional equilibrium where injurers do not take care and victims take care. This equilibrium entails higher social costs not only with respect to the other equilibrium with decoupling in which the social costs are 100, but also relative to the equilibrium with full compensation of the victim and no decoupling where the social costs are 105.

Because it is not possible to know *a priori* whether the bad or the good equilibrium will result with decoupling, some caution is required before applying Polinsky and Che's conclusion about the efficiency of decoupling in alternative care situations.

5.4. Punitive Damages

We have shown that, in situations in which victims' compensation is infeasible, precaution costs liability and regulation can solve the multiplicity problem, but we pointed that these solutions may be impractical or costly. We have also demonstrated that the *magnitude* of liability incurred by injurers cannot eliminate the inefficient equilibrium, but it can increase the chances of reaching the efficient outcome in a dynamic setting. This result is true even when the magnitude of liability is set at a level higher than social harm. Thus, our analysis provides a novel justification for imposing punitive damages, or more generally, harm based sanction in excess of social harm.

Interestingly, in contrast to other economic based rationale,³⁷ our new rationale for punitive damages is consistent with legal doctrine and practice in the U.S. according to which punitive damages are typically not awarded for economic harm but rather for physical harm, and in particular, serious bodily injuries and wrongful death cases.

In legal doctrine, the distinction between economic and physical harm, and specifically the health and safety of individuals, is rooted in the notion of the degree of "reprehensibility" of the conduct of the injurer, which is the most important indicium of the reasonableness of a punitive damages award.³⁸ According to our

is 140, hence cost of care must be no larger than 112.

³⁷The law and economic literature offers several explanations for the use of punitive damages. The main deterrence-related justifications are: the possibility of escaping sanctions, underestimation of harm, socially illicit gains, and inducing parties to bargain rather than acting unilaterally to cause harm. See, recently Sharkey (2012). See also, Polinsky and Shavell (1998), Shavell (2004, pp. 244–46), Shavell (2007), Posner (2007, pp. 206–7).

³⁸As Justice Kennedy put forward, in the landmark U.S. Supreme Court decision *State Farm*

argument, the distinction between economic and serious bodily injuries is relevant for the purpose of imposing punitive damages because it is related to the feasibility or infeasibility of victims' compensation. An economic harm, even if it is large, can be in principle compensated for, and if compensation is actually provided for the victim efficiency is uniquely attained. In contrast, physical harm, such as serious bodily injuries and death, cannot be compensated for ex-post, thereby facilitating the multiple equilibria problem.³⁹

Moreover, our rationale is consistent with the observation that in many practical cases punitive damages seem to be extremely high, in particular, when compared to compensatory damages. Under our setting, punitive damages or harm-based sanctions bear no clear relationship to the actual harm. Theoretically, they should be set as high as possible, as this would further increase the likelihood of attaining the efficient outcome.⁴⁰ In this regard, our argument, in contrast to other efficiency based rationales for punitive damages, such as the need for a damage multiplier to make up for the possibility that an injurer will escape suit, is immune to the criticism⁴¹ that juries do not normally engage in a finely tuned exercise of deterrence calibration when awarding punitive damages. Indeed, under our explanation, juries do not need to engage in such an exercise! If our argument is correct, then the trend in several jurisdictions to cap punitive damages as a multiple of actual damages, at least in several areas, is questionable.⁴²

Our analysis also sheds light on the difference between punitive damages and harm-based regulatory sanctions. Usually, it is not clear from standard analysis

Mutual Automobile Insurance Co. v. Campbell, in determining the reprehensibility of an injurer's conduct, courts are instructed to consider, among other things, whether "the harm caused was physical as opposed to economic" and "the conduct involved evinced an indifference to or a reckless disregard of the health and safety of others".

³⁹ It should be stressed that the distinction between economic and physical harm is not based on the idea that economic harm is generally lower than physical harm. Indeed, economic harm can be larger in magnitude than physical harm. Moreover, scholars who emphasize the fact that liability for serious bodily injuries and wrongful death is in effect too low, because, for example, it does not account for the hedonic value of life, usually advocate adjusting the level of liability so as to fully capture social harm (see, for example, Sharkey, 2012, pp. 10–12). In our analysis, when we discuss punitive damages we mean damages higher than social harm.

⁴⁰ We acknowledge that our analysis ignores possible costs associated with setting damages in excess of harm, such as the costs of over-deterrence. Arguably, the benefits we identify should be weighted against such costs.

⁴¹ See Justice Stevens' in *Cooper Industries v. Leatherman Tool Group, Inc.*: "[h]owever attractive such an approach to punitive damages might be as an abstract policy matter, it is clear that juries do not normally engage in such a finely tuned exercise of deterrence calibration when awarding punitive damages".

⁴² For example, Conn. Gen. Stat. Ann. sections 53-240b (West 2007) caps punitive damages at twice compensatory damages in produces liability cases.

whether punitive damages have some advantages or disadvantages over harm-based sanctions paid to a public body. As we have demonstrated, however, even if full or adequate compensation is infeasible, the magnitude of compensation also plays an efficiency role, because with higher compensation, it is more likely that the efficient outcome will be selected. This suggests that, in alternative care situations in which victims' full compensation is infeasible but partial compensation is feasible (for example, serious bodily injuries), punitive damages may in fact be more effective than harm-based public sanctions, because for a given level of "sanction", punitive damages can increase both liability and compensation while harm based public sanction affects only the liability. This suggests that the trend in several jurisdictions in the U.S. to order that some portion of punitive damages will go to various state funds is questionable.⁴³

5.5. *Liability insurance*

The classic role of insurance is to spread risks of risk averse parties. In the context of accidents, such role should be weighted against the possible adverse effects of insurance on incentives to take care. We have already briefly discussed in section 3.1 that in alternative care situations, a further role can be played by insurance, as an equilibrium selection mechanism. The reason is that insurance can provide compensation to the victims and therefore induce injurers to take care.

This conclusion applies also to liability insurance, as long as victim's compensation is feasible. For example, consider the case of judgement proofness, i.e. the victim is undercompensated because the injurer lacks resources to pay damages in full. In alternative care situations, liability insurance can be beneficial not only because it makes the injurer fully liable for the effects of his action (as is usually recognized) but also because it eliminates the inefficient equilibrium in which the victim takes care.

To illustrate, suppose that an injurer by taking precautions that cost 60 can prevent a 40% chance of an accident that would result in harm of 500 to the victim; the victim can also prevent the accident by taking precautions that cost 80. Suppose further that the injurer's wealth is 200. Since the injurer pays only

⁴³ Under Florida law, for example, 35% of any punitive damages award are paid to various state funds, on the ground that some portion of payments for quasi-criminal conduct should be paid to the state. Similarly, under Oregon law 60% of all punitive damages awards go to a Criminal Injuries Compensation Account (Epstein, 2008, p. 915).

200 in case of an accident, the victim is inadequately compensated (i.e., if the injurer does not take care, the victim would prefer to take care because $80 < 120 = 0.4 \times (500 - 200)$). Hence, there will be an equilibrium in which the victim takes care and the injurer does not take care.⁴⁴ However, if the injurer carries or is obliged to carry liability insurance, the victim will be fully compensated, and therefore will not take care. As a consequence, the efficient equilibrium where the injurer takes care will result.⁴⁵

It is important to recognize that, when injurers and victims are stuck in the inefficient equilibrium in which victims take care, injurers will have no incentives to buy liability insurance. A rule mandating that injurers will buy liability insurance which guarantees compensation for the victim may be recommended in this case.⁴⁶

Our conclusion that liability insurance is desirable is completely reversed if victims' compensation is infeasible, for example, because the accident results in serious injury or death. In these cases, liability insurance not only loses its efficiency based rationale, but it can aggravate the inefficiency identified in this paper.

To understand why, consider an injurer who can purchase full liability insurance; if coverage is not conditioned on his behavior, the injurer will have no incentives to take care. Anticipating that the injurer will not take care, the victim will be induced to take care, and the inefficient equilibrium will result. In equilibrium, since no accident occurs, the insurance premium will be very low (it will cover only administrative costs); as long as liability insurance shifts the cost of care to the victim, the injurer will find it in his interest to buy insurance coverage.⁴⁷

⁴⁴There is also the efficient equilibrium in which the injurer takes care and the victim does not take care, because if the victim does not take care, the injurer will prefer to take care since $60 < 0.4 \times 200$.

⁴⁵We should stress that this is true even if the probability of an accident when care is not taken is higher (e.g. 50%), so that expected harm calculated with such probability exceeds the injurer's wealth and is not affordable; indeed, the insurance premium will be zero (plus administrative costs) when it is set with reference to the equilibrium probability of accident.

⁴⁶That judgement proofness may reduce the incentive to buy liability insurance is recognized for example by Shavell (2005); however, in the circumstances we are considering the case for mandatory liability insurance is stronger due to the fact that lack of insurance, and therefore of compensation, has the effect of shifting the cost of care taking from injurers to victims.

⁴⁷In this case, too, we may want to distinguish between the case in which the victim can observe that a specific injurer is insured and the case in which she only knows the share of the population of injurers covered by insurance. In the former case, the injurer will have a definite incentive to buy insurance to signal that he will not take care and shift the cost of taking care to the victim. In the latter, there might be a collective action problem, because each individual injurer will have an incentive to free ride and save the cost of insurance.

In our framework, the usual justification why liability insurance is not harmful, but instead generally efficient, does not apply. The standard account of the effect of liability insurance (Shavell, 2000; Shavell, 2007) relies on the fact that either the insurer can observe the injurer's behavior, and therefore can condition coverage on such behavior to avoid moral hazard, or, if the insurer cannot observe the injurer's behavior, the injurer himself will choose a (second best) efficient level of coverage, i.e. a level of coverage which optimally trades off the reduced incentive to take care and risk coverage. The latter argument can be explained considering that, with full compensation of the victim through the tort system, all effects of the choice to buy insurance, including moral hazard, are internalized by the injurer.

This line of argument, however, does not apply to our case, because the impossibility to compensate victims together with the possibility that victims prevent the accident imply that the decision to buy insurance involves an externality. Indeed, the injurer and the insurance company will find it optimal to agree on a contract that induces moral hazard by the injurer, because this will shift (i.e., externalize) all the cost of care taking to the victim. Therefore, even if the insurer can observe the injurer's behavior, there is no incentive to make coverage conditional on such level; indeed, there is an opposite incentive. Furthermore, in case behavior cannot be observed, there is no incentive to refrain from purchasing full coverage, which makes not taking care an optimal strategy for the injurer.

To summarize, the desirability of liability insurance and, in particular, mandatory liability insurance, depends crucially on the possibility to use insurance to compensate victims.

6. Conclusion

In this paper we have analyzed situations in which either the victim or the injurer can prevent or reduce the expected harm from an accident by taking care, the injurer pays damages, but the victim is only partially compensated for her losses. Under these assumptions, the simultaneous interaction between the injurer and the victim has multiple equilibria, some of which are inefficient. We have shown that common liability rules cannot eliminate the possibility of an inefficient outcome, but precaution costs liability and regulation of injurers' behavior, although not always practical, can induce the efficient outcome uniquely. Moreover, in certain cases a solution to the multiplicity problem can be to alter the nature of the interaction between injurers and victims (and illustrated this with the Leading

Pedestrian Interval technique). Finally, we have shown that punitive damages can increase the likelihood that the efficient equilibrium is selected in a dynamic setting.

Moreover, we found that some standard results in the literature should be reconsidered and qualified. Because reliance on average harm to set damages implies partial compensation of (some) victims, our analysis provides a case for accuracy in the assessment of damages. For similar reasons, we concluded that caution is required before concluding that decoupling compensation from damages can be efficiency enhancing because it reduces legal costs for given level of deterrence. Finally, we showed that insurance can play a role that goes beyond pooling of risks: on the one hand, if the victim can be compensated in principle, (first party or liability) insurance may solve the problem posed by multiplicity of equilibria. On the other, if the victim cannot be fully compensated, liability insurance may actually exacerbate the problem identified in this paper, since injurers can use it as a commitment device. This suggests that it might be appropriate to prohibit the use of liability insurance in relevant situations.

APPENDIX

Care reduces but does not eliminate harm

We shall demonstrate how the multiplicity problem arises if care reduces but does not eliminate harm. Let ϵ be the probability of an accident if care is taken, where $0 < \epsilon < 1$, and assume that $x < y < (1 - \epsilon)h$, so that the costs of care are less than the expected benefits of care. The normal form game under strict liability transforms into:

		Injurer	
		Care	No Care
Victim	Care	$-y - \epsilon(h - m), -x - \epsilon k$	$-y - \epsilon(h - m), -\epsilon k$
	No Care	$-\epsilon(h - m), -x - \epsilon k$	$-(h - m), -k$

As can be verified, these changes in assumptions have no qualitative effect on our results. In particular, if we reduce all payoffs of the victim by $\epsilon(h - m)$ and all payoffs of the injurer by ϵk , this game is identical to the inadequate compensation game, with $(1 - \epsilon)(h - m)$ and $(1 - \epsilon)k$ playing respectively the role of $h - m$ and k in the original game.

When care does not eliminate the possibility of an accident, the distinction between negligence and strict liability becomes relevant. Suppose that the rule of negligence imposes liability on the injurer for the entire harm in case of an accident, unless the injurer took care. The normal form game is:

		Injurer	
		Care	No Care
Victim	Care	$-y - \epsilon h, -x$	$-x - \epsilon(h - m), -\epsilon k$
	No Care	$-\epsilon h, -x$	$-(h - m), -k$

The main result on multiplicity of equilibria and related results, hold straightforwardly as long as $x > \epsilon k$.

Otherwise, if $x < \epsilon k$, the injurer will have a dominant strategy to take care regardless of the victim's strategy. Since the interaction between the injurer and the victim may result in an accident even if care is taken, and since by taking due care the injurer relieves herself from liability for such accident, the injurer may have an incentive to take care even when the victim takes care.

Continuous care

We illustrate here how a situation with two Nash equilibria in pure strategy, one in which only the injurer takes care, the other in which only the victim takes care, can arise even when both parties' levels of care are continuous variables.⁴⁸

We consider two cases. In the first, we assume that what determines the probability of an accident is the maximum between the level of care of the victim and the injurer; this corresponds to the so called "best shot" case. In the second, we consider that the probability of an accident is a function of the sum of the injurer's and the victim's level of care, but taking care involves some fixed costs.

The best shot case. Let the probability of an accident be $p(z(x, y))$ where $p(z)$ is decreasing in z , and assume that $z(x, y) = \max \{x, ay\}$ with $a < 1$. In this case it is efficient that only the injurer takes care at a level x^* which minimizes $x + p(x)h$.

As there is no point in taking care for the victim if $ay \leq x$ and for the injurer if $x \leq ay$, there is no equilibrium in which both the injurer and the victim take

⁴⁸It is straightforward that multiple equilibria can arise if one party's strategy is binary (take or do not take care), while the other party's strategy is continuous.

care. If the victim does not take care and the injurer is fully liable for the harm caused ($k = h$), the injurer will minimize $x + p(x)h$ (cost of care plus expected liability) and take efficient care x^* . At the same time, if the injurer takes efficient care, the victim will prefer not to take care. In that case, efficiency is attained.

However, there is another equilibrium. If the injurer does not take care, the victim will take care to minimize $y + p(ay)(h - m)$. Let y^* denote such level of care, and observe that in general $y^* < x^*$. If the victim takes care y^* , the injurer will prefer not to take care as long as $p(ay^*)h < x^* + p(x^*)h$, that is, as long as $x^* > [p(ay^*) - p(x^*)]h$. For y^* close enough to x^* , i.e. for m sufficiently low and a sufficiently close to one, this inequality holds. Therefore, we have two possible Nash equilibria, one inefficient in which only the victim takes care, the other efficient in which only the injurer takes a level of care x^* .

The fixed costs case. As a second possibility, assume that $z(x, y) = x + y$ and that taking care involves fixed costs equal to a for the injurer and b for the victim, with $a < b$. Let $x^* > 0$ be the level of care that minimizes $a + x + p(x)h$ (this requires that $a + x^* + p(x^*)h < p(0)h$). It is efficient that only the injurer takes care at the level x^* .

Assuming that the injurer is fully liable for the harm ($k = h$) and that $m > 0$, the injurer prefers a joint level of care $x + y$ which is higher than the one preferred by the victim. If the victim does not take care, the injurer will take efficient care x^* . At the same time, if the injurer takes care x^* , the victim will prefer not to take care, because her preferred joint care level is lower than the one preferred by the injurer. Efficiency is reached.

However, there is another possible equilibrium. If the injurer does not take care, the victim will take care at a level y^* that minimizes $b + y + p(y)(h - m)$.⁴⁹ If the victim takes care y^* , the injurer will prefer not to take care as long as $p(y^*)h$ (his expected liability if only the victim takes care) is lower than $a + (x^* - y^*) + p(x^*)h$ (his costs of care and expected liability if he increase total care to the preferred level x^*). That is, the injurer will prefer not to take care as long as $a + (x^* - y^*) > (p(y^*) - p(x^*))h$. This inequality holds whenever x^* is sufficiently close to y^* (i.e. when m is sufficiently small) and a is sufficiently large. Hence, when the last inequality holds, we have two possible Nash equilibria, one inefficient in which only the victim takes care, the other efficient in which only the injurer takes a

⁴⁹ It will be $y^* > 0$ provided that $b + y^* + p(y^*)(h - m) < p(0)(h - m)$, i.e. when m and b are sufficiently small.

level of care x^* .⁵⁰

Asymptotic properties of the Nash equilibria NE1, NE2 and NE3

We shall derive in this part the replicator dynamics equations and analyze the stability properties of the system. Assuming that the growth rate \dot{p}/p is equal to the difference between the payoff of an injurer who takes care and the average payoff of the population of injurers, $-x - (-px - (1-p)(1-q)K)$, and similarly assuming that \dot{q}/q is equal to the difference $-y - (-qy - (1-q)(1-p)(h-m))$, we obtain the following replicator equations:

$$\dot{p} = p(1-p)[(1-q)k - x] \quad (1)$$

$$\dot{q} = q(1-q)[(1-p)(h-m) - y]. \quad (2)$$

It is easy to check from (1)–(2) that the fixed points (p, q) of the dynamics system are: $(1, 0)$, $(0, 1)$, $(0, 0)$, $(1, 1)$ and $\left(\frac{h-m-y}{h-m}, \frac{k-x}{k}\right)$. In order to analyze their stability properties, we calculate the Jacobian:

$$J = \begin{bmatrix} (1-2p)[(1-q)k - x] & -p(1-p)k \\ -q(1-q)(h-m) & (1-2q)[(1-p)(h-m) - y] \end{bmatrix} \quad (3)$$

local stability depends on the sign of the eigenvalues:

- (a) At $(0, 1)$ we have $J = \begin{bmatrix} -x & 0 \\ 0 & m + y - h \end{bmatrix}$, and the eigenvalues are $\lambda_1 = -x < 0$ and $\lambda_2 = y + m - h < 0$, so that the fixed point is asymptotically stable. Similarly, at $(1, 0)$ we have $J = \begin{bmatrix} x - k & 0 \\ 0 & -y \end{bmatrix}$, and the eigenvalues are $\lambda_1 = x - k < 0$ and $\lambda_2 = -y < 0$. Therefore $(0, 1)$ and $(1, 0)$ are asymptotically stable fixed points.

- (b) At $\left(\frac{h-m-y}{h-m}, \frac{k-x}{k}\right)$ we have

$$J = \begin{bmatrix} 0 & -\frac{k-x}{k} \frac{x}{k} (h-m) \\ -\frac{h-m-y}{h-m} \frac{y}{h-m} k & 0 \end{bmatrix} \quad (4)$$

⁵⁰ Because $x^* > y^*$, there are no pure strategy Nash equilibria in which both parties provide a positive level of care. If $x^* = y^*$, for example because $m = 0$, there might be additional Nash equilibria with levels of care x and y such that $x + y = x^*$; however, such equilibria require that a and b are sufficiently close to zero.

the eigenvalues are $\lambda_1 = \sqrt{xy(k-x)(h-m-y)/k(h-m)} > 0$ and $\lambda_2 = -\lambda_1 < 0$. The fixed point is unstable (more specifically, it is a saddle point, with a stable and an unstable manifold: see below).

(c) At $(0, 0)$ we have $J = \begin{bmatrix} k-x & 0 \\ 0 & h-m-y \end{bmatrix}$ with eigenvalues $\lambda_1 = k-x > 0$

and $\lambda_2 = h-m-y > 0$. At $(1, 1)$ we have $J = \begin{bmatrix} x & 0 \\ 0 & y \end{bmatrix}$ with eigenvalues $\lambda_1 = x > 0$ and $\lambda_2 = y > 0$. In both cases all eigenvalues are positive, and the fixed points are unstable (these fixed points are not equilibria, they correspond to situations where the replicator dynamics does not allow for the appearance of strategies which are not present in the population in the first place).

For further reference, it is useful to specify that if we linearize the system and center it around $(\frac{h-m-y}{h-m}, \frac{k-x}{k})$, the stable manifold is described by the increasing line

$$(J_{11} - \lambda_2)p + J_{12}q = \sqrt{\frac{xy(k-x)(h-m-y)}{k(h-m)}} \cdot p - \frac{k-x}{k} \frac{x}{k}(h-m) \cdot q = 0 \quad (5)$$

and the unstable manifold by the decreasing line

$$(J_{11} - \lambda_2)p + J_{12}q = -\sqrt{\frac{xy(k-x)(h-m-y)}{k(h-m)}} \cdot p - \frac{k-x}{k} \frac{x}{k}(h-m) \cdot q = 0. \quad (6)$$

The dynamics is illustrated by the phase diagram in figure 1.

Effect of damages and compensation on the basin of attraction

We prove in this part that higher damages or compensation increase the basin of attraction of the efficient equilibrium. We do so by showing that both an increase in k and an increase in m extend the basin of attraction of $(0, 1)$ so that it includes the initial saddle path. In other words, we take a generic point (p_0, q_0) lying on the saddle path when damages and compensation are k' and m' respectively, and show that, with $k'' \geq k'$ and $m'' \geq m'$ (where either one or the other inequality is strict) the new trajectory originating from this point converges to $(1, 0)$.

The slope of a trajectory passing from (p, q) can be obtained from (1) and (2) by eliminating time:

$$\frac{dq}{dp} = \frac{q(1-q)}{(1-q)k-x} \bigg/ \frac{p(1-p)}{(1-p)(h-m)-y}. \quad (7)$$

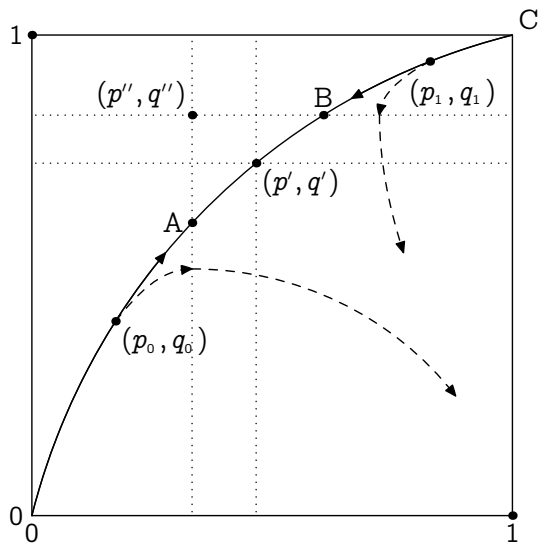


Figure 3. Effect of a higher k and/or m on trajectories starting from the saddle path

Let (p', q') be the saddle point with k' and m' , and (p'', q'') be the new saddle point with k'' and m'' —with $q'' > q'$ if and only if $k'' > k'$ and $p'' < p'$ if and only if $m'' > m'$. Figure 3 shows that the new saddle point identifies three distinct portions (0A, AB and BC) of the old saddle path.

First note that, with k'' and m'' , whenever $p \geq p''$ and $q \leq q''$, with either one or the other inequality strict, (p, q) converges to the efficient equilibrium $(1, 0)$. This will be the case of any point (p_0, q_0) belonging to the portion AB of the saddle path.

Consider now a generic point on the portion 0A of the initial saddle path. Such a point satisfies $(p_0, q_0) < (p'', q'')$. Note that the slope dq/dp is positive as long as $p < p'$ and $q < q'$, and it will be lower with k'' and/or with m'' than with k' and m' ; therefore, starting from (p_0, q_0) the new trajectory lies below the old trajectory. Since the latter coincides with the saddle path and converges to (p', q') , the new trajectory will reach $q < q' < q''$ when $p = p'$, and the system will eventually converge to $(1, 0)$.

Similarly, consider a point (p_1, q_1) on the portion BC of the initial saddle path. It will be $(p_1, q_1) > (p'', q'')$. In this case, the slope of the trajectory, is higher with k'' and m'' than with k' and m' , and the new trajectory will be again below the old one. Therefore, on the new trajectory starting from (p_1, q_1) it will be $p > p'$ when $q = q''$, and the system will eventually converge to $(1, 0)$.

Accuracy in the assessment of damages

We provide here a formal characterization of the results in section 5.2.

Assume that there is a proportion $\alpha \in (0, 1)$ of victims who suffer a high loss h_H and a proportion $1 - \alpha$ of victims who suffer a low loss h_L if an accident occurs, and that victims know the potential loss they will suffer (i.e. their type) but injurers do not know it ex-ante. Care reduces the probability of accident from 1 to ϵ for either type of victim. With⁵¹

$$x < y < (1 - \epsilon)h_H \quad (8)$$

and

$$x < \alpha y + (1 - \alpha)(1 - \epsilon)h_L \quad \text{if} \quad y > (1 - \epsilon)h_L, \quad (9)$$

efficiency always mandates that only the injurer takes care. In order to minimize social cost, a strict liability rule is imposed.⁵²

Consider that damages k are based on average harm, calculated with respect to the distribution of accidents in equilibrium. When care is taken with both high and low loss victims (i.e. when either injurers or both types of victims take care), the average harm conditional on an accident taking place is

$$\bar{h}_c = \alpha h_H + (1 - \alpha)h_L. \quad (10)$$

The (conditional) average harm is of course the same when care is not taken by anyone (i.e. neither injurers nor victims of any type take care). When instead only high loss victims take care, while neither low loss victims nor injurers do, the conditional average harm is

$$\bar{h}_{nc} = \frac{\epsilon \alpha}{1 - (1 - \epsilon)\alpha} h_H + \frac{1 - \alpha}{1 - (1 - \epsilon)\alpha} h_L; \quad (11)$$

⁵¹If injurers always take care the social costs are $x + \alpha \epsilon h_H + (1 - \alpha)\epsilon h_L$ while if injurers do not take care but high loss victim take care social costs are $\alpha(y + \epsilon h_H) + (1 - \alpha)h_L$. Note that if injurers were able to distinguish between low loss and high loss victims, it would be efficient that they did not take care when meeting a low loss victim if $x > (1 - \epsilon)h_L$. Under the assumption that they do not know a priori whether the victim is high loss or low loss, conditions (8) and (9) identify (second best) efficient solutions.

⁵²This implies that the injurer is liable even if $x > (1 - \epsilon)h_L$. With a negligence rule things would be more complicated, because it would not be obvious whether courts define negligence on a case by case basis, so that injurers are not found negligent with respect to low loss victims if $x > (1 - \epsilon)h_L$, or with reference to the average harm in the population. We disregard this case to keep the analysis simple.

note that as ϵ tends to zero \bar{h}_{nc} approaches h_L . To summarize, average damages are $k = \bar{h}_{nc}$ if neither injurers nor low loss victims take care while high loss victims take care; it is $k = \bar{h}_c$ in all other relevant cases. We ignore the case where only low loss victims take care because, as it will be clear below, this cannot be part of an equilibrium. Individual deviations from equilibrium behavior either by injurers or by victims do not affect k because the population is large and the impact of individual behavior is negligible.⁵³

We prove the following:

Lemma 1. *There always exist values of x and y such that there is a Nash equilibrium in which injurers do not take care, high loss victims take care, and $k = \bar{h}_{nc}$, provided that $(2 - \alpha)h_L < h_H$ and ϵ is sufficiently small. \square*

PROOF. Consider now the case that high loss victims take care and injurers do not take care. Damages are $k = \bar{h}_{nc}$, so that injurers will have no incentive to take care if

$$x > (1 - \alpha)(1 - \epsilon)k. \quad (12)$$

and, when injurers do not take care, taking care will be the optimal strategy for high loss victims if⁵⁴

$$y < (1 - \epsilon)(h_H - k) \quad (13)$$

On the other hand, injurers' care is efficient when

$$\begin{cases} x < y & \text{if } x \leq (1 - \epsilon)h_L \\ x < (1 - \epsilon)(\alpha y + (1 - \alpha)h_L) & \text{if } (1 - \epsilon)h_L < y. \end{cases} \quad (14)$$

Since $\lim_{\epsilon \rightarrow 0} \bar{h}_{nc} = h_L$, there exists $\epsilon > 0$ sufficiently small such that if $(2 - \alpha)h_L < h_H$ we have $(2 - \alpha)\bar{h}_{nc} < h_H$. Consider any y satisfying $(1 - \alpha)(1 - \epsilon)\bar{h}_{nc} < y < (1 - \epsilon)(h_H - \bar{h}_{nc})$. Then, if $y \leq (1 - \epsilon)h_L$, consider x such that $(1 - \alpha)(1 - \epsilon)\bar{h}_{nc} < x < y$; otherwise, if $y > (1 - \epsilon)h_L$, consider x such that $(1 - \alpha)(1 - \epsilon)\bar{h}_{nc} < x < \alpha y + (1 - \alpha)(1 - \epsilon)h_L$. It is trivial to check that for $k = \bar{h}_{nc}$ such values of x and y satisfy conditions (12)–(14). \square

⁵³We are not considering coordinated deviations of a large number of individuals from the equilibrium strategy. A high number of high cost victims deciding not to take care could modify the average h and hence the value of k . Moreover, k may be modified with a lag with respect to changes in individuals' behavior.

⁵⁴Note that if $y > (1 - \epsilon)(h_H - \bar{h}_{nc})$ victims have a dominant strategy not to take care; if $x < (1 - \alpha)(1 - \epsilon)\bar{h}_{nc}$ injurers will have a dominant strategy to take care; under either circumstance, the only possible equilibrium is the efficient one in which injurers take care and no victim takes care.

This result does not apply if average damages are set with reference to the underlying distribution of harm in the population of potential victims. More formally:

Lemma 2. *Assume $k = (1 - \alpha)h_L + \alpha h_H$. For all possible values of h_L , h_H , α , x and y , there is no Nash equilibrium in which injurers do not take care and high loss victims take care.* \square

PROOF. We need to show that inequalities (12), (13) and (14) are never simultaneously satisfied when $k = \alpha h_H + (1 - \alpha)h_L$. Suppose first that $x < y \leq (1 - \epsilon)h_L$. Conditions (12) and (13) require that $(1 - \alpha)k < (h_H - k)$, which implies that $h_L(2 - \alpha)/(1 - \alpha) < h_H$. On the other hand, the condition $(1 - \alpha)(1 - \epsilon)k < x$ together with $x < (1 - \epsilon)h_L$ imply that $(1 - \alpha)k < h_L$, which leads to the contradiction $h_L(2 - \alpha)/(1 - \alpha) > h_H$.

If instead $y > (1 - \epsilon)h_L$, the necessary condition for efficiency requires that $x < \alpha y + (1 - \alpha)(1 - \epsilon)h_L$. Together with $y < (1 - \epsilon)(h_H - k)$, we obtain $x < (1 - \epsilon)(\alpha(h_H - k) + (1 - \alpha)h_L) = (1 - \alpha)(1 - \epsilon)k$, which contradicts the condition $(1 - \alpha)(1 - \epsilon)k > x$. \square

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