Causation and the Incentives of Multiple Injurers

Lando, Henrik; Schweizer, Urs

Document Version
Final published version

Published in:
International Review of Law and Economics

DOI:
10.1016/j.irle.2021.106026

Publication date:
2021

License
CC BY

Citation for published version (APA):
Lando, H., & Schweizer, U. (2021). Causation and the Incentives of Multiple Injurers. *International Review of Law and Economics*, *68*, Article 106026. https://doi.org/10.1016/j.irle.2021.106026

International Review of Law and Economics 68 (2021) 106026

Contents lists available at ScienceDirect

International Review of Law and Economics

Causation and the incentives of multiple injurers

Henrik Lando[a,*], Urs Schweizer[b]

[a] Law and Economics, Copenhagen Business School, Denmark
[b] Economics, University of Bonn, Germany

ARTICLE INFO

Article history:
Received 5 April 2021
Received in revised form
16 September 2021
Accepted 23 September 2021
Available online 27 September 2021

JEL classification:
K13
D02

Keywords:
But-for causation
Multiple sufficient causation
NESS-test
Shapley apportionment
Compensation principle

ABSTRACT

Under the but-for requirement of causation, a tort injurer cannot be held liable for more than the difference between the loss the victim would have suffered if the injurer had not been negligent, and the loss that is in reality suffered. We ask whether this causation requirement yields efficient precaution in the context of two or more injurers. Contrary to a widely accepted view, we find that but-for causation may lead to the existence of an inefficient Nash-equilibrium. We characterize when this may occur and compare those instances with precedent in which courts have not required but-for causation. Moreover, we ask whether alternative concepts of causation do better than but-for causation in terms of incentives. We find that while both the NESS-test and the Shapley provide optimal incentives when injurers act simultaneously, there are reasons for considering the Shapley-value as the more satisfactory concept of causation.

1. Introduction

The concept of but-for or necessary causation as applied to tort or nuisance law seems to provide optimal incentives for taking precautions under a negligence rule, as an injurer can be held liable for the harm that would not have occurred but for the injurer's negligent act. This seems to provide proper internalization of harm. However, it is well-known that this appearance can be deceptive in the context of multiple injurers, where but-for causation can lead to counterintuitive results. As we shall demonstrate, this may occur in (only) three distinct types of situations.

As the first type of situation, referred to as concurrent causation, two injurers can perform a negligent act independently of each other, which on its own is sufficient for the full harm to occur. For instance, two people can simultaneously light a fire that burns down a house, or two firms can both pollute a river. In such situations, but-for causation would hold neither party liable as neither of them is a necessary cause of the harm. Courts have then sometimes responded by considering a person to have caused the harm when the person's negligence was sufficient for the harm to occur.[1]

The second type of situation occurs when there are more than two injurers and a subgroup of injurers sufficiently cause the harm. If, for instance, three injurers push a car over a cliff and the push of two of them would suffice, then each injurer's act is neither necessary nor sufficient for the harm to occur.[2] For such scenarios, it is not enough to consider sufficient harm as a form of a causation; the most recent Restatement (Third) instead suggests expanding the concept of causation though the NESS-test which establishes causation when the injurer is a member of a group of injurers whose negligent acts are sufficient for the injury, provided that the injurer's negligence is necessary for that sufficiency.[3]

As for the third type of situation, consider a doctor prescribing a wrong drug for treatment of a patient's disease and a nurse failing

[1] An early common law case on this theme is Cook v. Minneapolis, St. P. & S. Ste. M. Ry.

[2] This example dates back to Carpenter (1934) and is mentioned also in the Restatement (Third) of Torts: Liability of Physical and Emotional Harm, §27, cmt. f, ill. 3, (American Law Institute, 2009).

[3] The Restatement (Second) advocated a substantial factor test, according to which a party is considered to have caused a loss if the party's act was a substantial factor in creating the loss. This test raises the question of what it means for an act to be a substantial factor.

* Corresponding author.
E-mail addresses: hl.law@cbs.dk (H. Lando), schweizer@uni-bonn.de (U. Schweizer).

https://doi.org/10.1016/j.irle.2021.106026

to apply the drug to the patient, thereby inadvertently saving the patient's life. If the lack of treatment leads the patient to suffer a setback, there is actual harm, but the marginal harm from the nurse's failure to treat the patient is negative – it saves the patient's life – while the marginal harm caused by the doctor is zero, as the falsely prescribed drug is not actually applied.[4]

In these three types of situations, but-for causation appears to yield sub-optimal internalization of harm. However, this has been contested in the law and economics literature; indeed, the conventional view is that multiple sufficient causation does not provide ground for expanding the concept of causation. This view stems from the surprising finding by Shavell (1980) that there always exists an efficient Nash equilibrium under the but-for causation requirement, even when, as in the three examples, no injurer will be held liable. The logic of this finding is that it is an equilibrium for all to take due care, since if every injurer expects the others to take due care, it is optimal for every injurer to also take due care.[5] This view has been criticized by some legal scholars who have seen it as proof that analyzing causation from the perspective of efficiency and incentives is unproductive. Thus, Wright (1985) claims that (p. 447):

> ..the courts have imposed liability... in the duplicative causation cases. Thus, from both the normative and positive perspectives, Shavell's theory fails.

However, as one of the main contributions of this article, we demonstrate that efficiency considerations do not lead to the conventional view; there can be a reason to expand the concept of causation, we show, when (and only when) the harm-function is sub-modular in the sense that the injurers' marginal contributions to harm do not add up to total harm. There then exists an efficient and can also exist an inefficient Nash equilibrium under the but-for causation requirement. Our analysis hence brings the law and economic analysis of causation closer to precedent and to a common intuition.

Our result, in turn, raises the question of how to expand the concept of causation in order to achieve optimal incentives when the harm function is sub-modular. We consider mainly three possibilities: one is to regard an injurer as having caused a loss not only if his negligence is necessary but also if it is sufficient for the loss to occur; another is to apply the NESS-test as advocated by the Restatement (Third); and the third is to apply the Shapley value. These notions of causation can be characterized in terms of how they incorporate information about injurers' marginal contributions to harm in different hypothetical scenarios. The hypothetical scenarios differ in terms of which injurers act negligently and which (counterfactually) do not. An injurer's marginal contribution to harm can be measured in any scenario and the different possibilities for expanding the notion of causation can be understood in terms of which scenarios they consider. For instance, the expansion which considers sufficient cause as causation simply examines, for any injurer, whether the harm that actually occurs is also incurred in a scenario in which only that injurer is negligent. As mentioned, the NESS-test on the other hand regards an injurer as having caused a given injury (to a good), if two conditions are fulfilled: first, there is a subgroup of negligent injurers, which includes the injurer, whose acts are sufficient for causing the injury. And second, the injurer's negligence is necessary for this group's negligence to be sufficient. Finally, the Shapley value differs from the NESS-test in two dimensions. First, it does not consider an individual injurer's marginal contributions to physical injury but to harm in monetary terms. It turns out that there can be a difference if a negligent act causes injury to one good but saves another good. Second, the Shapley value considers each injurer's average marginal contributions to the victim's monetary losses over all possible hypothetical scenarios in which one or more injurers act negligently. To illustrate, if there are three injurers, the Shapley value considers three possibilities: that the injurer is the only one who acts negligently, that there is one other injurer who also acts negligently and finally that the two others also act negligently. It averages the injurer's marginal contributions to harm across these three possibilities. Note that the NESS-test and the Shapley consider the same marginal contributions of injurers but where the Shapley value averages the contributions over all scenarios, the NESS-test looks for a hypothetical scenario in which an injurer's marginal contribution is the actual injury.

One of our main findings is that both the NESS-test (and so also the concept of causation which regards not only necessary but also sufficient cause as causation) and the Shapley value ensure optimal incentives, essentially because they ensure full compensation to the victim and full compensation ensures efficiency of the Nash-equilibrium in the game between the injurers. However, we find reasons to prefer the Shapley value to the NESS-test in part because the Shapley value is concerned with values lost (and therefore can take into account scenarios that involve more than one good where a negligent act can save a good as in the third example above) and in part because the Shapley value lives up to a set of desirable axioms of apportionment.

Apart from the NESS-test and the Shapley value, some alternative notions of causation are sometimes applied, particularly when it is difficult to measure harm in hypothetical scenarios. For instance, but-for causation may be taken to mean that an injurer has caused a loss if the loss would not have occurred if the injurer had not undertaken the activity rather than if the injurer had not undertaken the activity in a negligent manner. Or sometimes causation requirements are dispensed with by courts who consider two injurers to be jointly liable if the loss would not have occurred had neither party acted negligently. Our framework allows us to also determine whether these and other similar rules are efficient.

As for the structure of the article, we have found it necessary to begin by defining but-for causation and by considering how the concept plays out when there is limited measurability of the consequences of hypothetical acts. We then provide an overview of the literature before presenting two examples that illustrate the gist of our analysis. After having presented the model and derived our main results, we compare them with legal practice. Finally, we comment on our results and their limitations before concluding.

2. On the meaning of but-for causation

There exist mainly two notions of but-for causation. One restricts a negligent injurer's liability to that amount of the actually incurred loss which would have been avoided if the injurer had acted with due care. We shall refer to this as the but-for-negligence rule.[6] The other restricts liability to the loss that would have been avoided if the injurer had not undertaken that activity which he conducted in a negligent manner. We shall refer to this as the but-for-activity rule.[7]

The difference between the two rules can be illustrated by Kahan's example: if due care requires the wall to a cricket field to be ten feet tall, and the owner builds it only nine feet tall and so acts with negligence, the owner will be held liable under the but-

[4] We have not yet found legal cases of this nature and such cases are not directly addressed in the Restatement (Third).

[5] This argument is also made by Landes and Posner (1980, p. 524).

[6] It is referred to as the P^* rule by Grady (1983) and Kahan (1989) considers this to be simply the rule of but-for causation.

[7] In Grady's definition, for there to be causation there must be some level of precaution, perhaps a very high one, which would have prevented the loss.

for-activity rule but not under the but-for-negligence rule if the cricket ball flies above the wall at a height of more than ten feet.[8]

There is near agreement in the literature that the rule applied by courts is the but-for-negligence rule, see, e.g. Wright (1985, pp. 1759–1774), with an extensive discussion including references to proponents of the but-for activity rule, Kahan (1989), and Landes and Posner (1983, p. 115), with several examples of the use of the but-for-negligence rule.[9] The Restatement (Third) (American Law Institute, 2009, chapter 5, §26 (illustration)) clearly regards but-for causation as but-for-negligence:

> While driving 57 miles per hour on a road with a 50-miles-per-hour speed limit, Ken ran into Melanie, a pedestrian. Ken is not subject to liability for negligence in speeding unless he would not have hit Melanie or would have caused her less harm if he had been driving 50 miles per hour.

It is then worth for us to explain why we will also consider the effects of the but-for-activity rule, and why in the context of multiple injurers we will even address the consequences of a rule that holds both injurers liable for losses jointly caused in a sense to be defined below. We do so because the but-for-negligence rule can turn into the but-for-activity rule (or even into a rule of joint liability for harm jointly caused) when there is lack of evidence concerning what the loss would have been if the injurer had acted with due care.

In the context of Ken's negligent driving, it may often be difficult to know how great the harm from an accident would have been if Ken had driven at 50 miles an hour. For that reason, a court might apply the but-for-activity rule even if it would ideally wish to use the but-for-negligence rule. This policy is explicitly stated by the Restatement (Third) for the case of multiple injurers. It requires the victim to prove that an injurer's negligence caused some part of damages[10] and when the victim has proven this, the defendant must present evidence that makes it possible to divide the victim's losses by causation, i.e. which allows for a quantification of the damages separately caused by the injurer's negligence (see Restatement (Third) American Law Institute, 2000, Topic 5, §26, p. 320).[11] If the injurer or the fact-finder cannot provide such evidence, the injurer is considered to have caused the full amount of damages.

This rule, however, allows for a couple of interpretations as the following example illustrates: Two firms are individually only allowed to emit 10 units, otherwise they are considered negligent. One firm, *A*, emits 15, and another firm, *B*, emits 25. The table shows the levels of harm in monetary terms as a function of acts taken by the two negligent firm, when harm equals total emissions squared:

	B emits 25	B emits 10 (due care)	B emits 0
A emits 15	1600	625	225
A emits 10 (due care)	1225	400	100
A emits 0	625	100	0

We assume that the loss is zero if neither party emits, as losses are measured by comparison with what would happen if neither party emitted (participated in the activity). Applying the divisibility rule of the Restatement (Third) (§26) to this example, it must mean that if the fact-finder can with reasonable accurateness measure the numbers 1600 and 1225, their difference will be the loss caused by *A* (similarly for *B*). If, however, this difference is not measurable, it is not clear which rule applies. It may be the but-for-activity rule, in which case *A* is the cause of $1600 - 625$. However, if this is also not measurable, it may be that *A* should be considered the cause of the actual loss of 1600 in which case *A* and *B* (if *B*'s causation also cannot be measured) will be in effect jointly liable for 1600.

Hence, the measurability or divisibility problem takes on added importance in the context of multiple injurers and may lead to rules that in effect dispense with individual causation requirements. We point this out, since it will lead us to also investigate the practically relevant question of whether incentives are correct when there is limited measurability.

A further conceptual issue is whether but-for causation means that it is required that the injurer's negligence must have caused the accident, or the injury, or the victim's monetary loss. Note first, that it cannot be the accident, at least not according to the Restatement (Third). In the example above, if Ken would have driven into Melanie had he driven with due care, he would still be liable if there is a difference in harm caused by the excessive speed. But does but-for causation then concern the actual injury or the loss in terms of value to the victim? The difference is clear in the example mentioned in the introduction of the doctor and nurse where the question is whether the patient's deterioration in health due to the lack of treatment is all that matters to the causation rule or whether offsetting benefits matter in the calculation of what each injurer causes. If causation concerns value lost, one must consider also offsetting benefits, i.e. consequences of negligence (whether positive or negative) to other goods than those actually harmed. We believe that causation should be considered in value terms, but we will consider the consequences also of disregarding offsetting benefits.[12]

Finally, it is worth addressing the meaning of the term joint (or in a civil law context, solidary) liability, which is sometimes viewed as a rule of causation. Joint liability, however, is a rule that decides the way in which injurers, who have all caused a loss, share liability for it. The application of the rule of joint liability hence presupposes that the injurers have all caused the given loss. Joint liability means that the victim can claim the full loss with either of the injurers. If liability is only several, the victim can only hold the individual injurer liable in proportion to his or her relative culpability (degree of negligence), see §11 of the Restatement (Third) (American Law Institute, 2000).

As mentioned above, we shall also consider the consequences of a rule that ignores individual causation requirements and that, due to the difficulty of measurement, imposes joint liability on injurers who have jointly caused a loss in the sense that the loss would not have occurred if neither injurer had acted negligently.

[8] A third rule, which Grady advocates and believes to be enforced in common law, holds the negligent injurer liable for losses that could have been avoided by a measure that passes the cost-benefit test. This is not the same as the but-for-negligence rule, as Grady's example illustrates in which a person has drowned in a pool which the owner could have made safer by a fence or by the hiring of life guards. The fence would have avoided the accident whereas it cannot be established that the life guards would have. Establishing a fence may have been excessive precaution, life guards may have been sufficient – yet the building of the fence may still pass a cost–benefit test compared with no precaution. According to Grady, the court will not deny compensation on the grounds that it cannot be shown that the victim would not have drowned if there had been life guards. We shall briefly address also this rule.

[9] Although Grady is skeptical that courts actually enforce the but-for negligence rule, this is because he thinks they enforce his cost-benefit described in the footnote[8], which is a modification of the but-for-negligence rule; it is not because he believes the actual rule is the but-for-activity rule.

[10] This replaces the requirement of the Restatement (Second) (American Law Institute, 1979) that the victim proves that the injurer's act was a "substantial factor".

[11] We note that §26 is not easy to interpret, as it is not clear for what amount the plaintiff seeks recovery; this amount must be determined by the rule of causation which the rule is meant to establish.

[12] We are aware that offsetting benefits are quite rare in legal practice, but we are interested in developing a general theory of causation, not only one that works well under most circumstances.

3. The literature

We list but do not review the general law and economics literature on causation; our review is in the main confined to the literature concerning multiple injurers and in particular multiple sufficient causation.

The list of early, general literature includes Calabresi (1975), Shavell (1980), Landes and Posner (1980), Grady (1983), Kornhauser and Revesz (1989), Cooter (1987), and Kahan (1989). More recent contributions are Young et al. (2007), Parisi and Singh (2010), Miceli and Segerson (1991), Hylton (2013), Hylton and Lin (2015), Carvell et al. (2012), Deffains et al. (2016), and Dillbary (2013, 2016). An overview of the main topics and the literature can be found in Ben-Shahar (2009), Hylton (2013) and Deffains et al. (2016).

As for the literature on multiple injurers, Shavell (1980) seems to have been the first to provide a formal model. He demonstrates that for strict liability there exists an efficient Nash equilibrium under the but-for causation requirement, and he adds that this holds also for the rule of negligence. This finding includes, as mentioned, the case of multiple sufficient causation. We extend his result by showing the existence of an inefficient Nash equilibrium under the negligence rule[13] when the harm-function is sub-modular, as when there is multiple sufficient causation.

Landes and Posner address the issue of causation in Landes and Posner (1983) and of multiple injurers in Landes and Posner (1980). In Landes and Posner (1983), they argue that the but-for-negligence rule is optimal from an efficiency viewpoint, since it does not improve the incentive for an injurer to act with due care to hold him or her liable for a loss that would have occurred even if he or she had acted with due care. They do not address the point we are raising, namely that this logic may not apply in the context of multiple injurers where the causation requirement may shift the equilibrium.

Kornhauser and Revesz (1989) (K & R) analyze different legal rules for sharing losses among multiple injurers that at their time of writing were associated with CERCLA[14] . In particular, they analyze the way in which joint or joint and several liability was at that time administered under CERCLA. Since these rules were administered without much concern for individualized causation requirements, only some of their analysis is relevant in our context. Hence, in terms of our example above, they consider that the victim could, under a rule of joint liability, raise a claim of either $1600 - 400$ under a rule which they term partial liability, or a claim of 1600 under a rule which they term full liability, against any of the two negligent injurers. Hence, under CERCLA joint liability was a rule that restricted each negligent injurer's liability to the loss jointly caused by the negligent injurers (including, in some variants, losses caused by non-negligent injurers), without consideration of what each negligent injurer had individually caused.[15] Later, individualized causation was increasingly taken into account, and individual causation became a constraint on apportionment when divisibility could be established, as described by Boston (Boston, 1995, pp. 103–104).[16]

Grady (1990) considers whether multiple injurers have sufficient incentives for care under the negligence rule, and is skeptical in this regard (see, e.g. p. 675). He does not, however, formalize his intuition that there may not be enough incentives if the parties share liability for a loss.[17] We believe that this intuition conflicts with our compensation principle, which states that as long as the parties together cover the full loss, there does not exist an inefficient Nash equilibrium when the harm function is super-modular, which is the main case Grady considers (following K & R).[18]

In a reconsideration of the theory of causation, Hylton (2013, p. 11) addresses multiple sufficient causation. He suggests that the court's finding of causation in such cases is based on the fear that legal errors may otherwise lead to inefficient incentives. We see his and our rationale as complementary.

Dillbary (2016) mentions the possibility that there may be inefficient incentives under but-for causation when there is multiple sufficient causation. One possibility analyzed by Dillbary is the tort-fest, in which the marginal liability of each injurer falls as many injurers join in creating harm for which each injurer is the sufficient cause. The tort-fest may be efficient even though courts require care by all injurers; thus, in contrast to the present analysis, Dillbary's theory covers the situation where courts set negligence standards inefficiently. Therefore, his and our conclusions are not directly comparable. However, one of his conclusions differs from ours for a reason unrelated to standards being set inefficiently: Dillbary concludes that but-for causation does not need amendment to take multiple sufficient causation into account, for when two injurers' acts duplicately cause a given harm both acts can be said to be the but-for cause of the harm, as neither injurer would have acted negligently if it were not for the negligent act of the other. We question this point when injurers act simultaneously, since then they do not know each other's act but only guess it correctly in the Nash equilibrium.

Dehez and Ferey (2013), Ferey and Dehez (2016) and Ferey and Dehez (2016), the latter in a symposium on causation and apportionment printed in Kent Law Review in 2016 (Wright et al., 2016) analyze the use of the Shapley value as a measure of causation mainly in the context of sequential choice, emphasizing its desirable axiomatic properties. They briefly note that the Shapley value may not lead to efficiency (in a sequential setting), but are more concerned with fairness than with incentives.

There is a vast legal literature on causation, a list too long to outline here. Some references are Hart and Honoré (1985), Peczenik (1979), and Wright (1985). Among the contributions concerned with multiple sufficient causation are Fischer (1992), Green and Williams (2005), and Robertson (2009).

On off-setting benefits, we have found only the article by Porat and Posner (2014) within the law and economics literature. It considers whether off-setting benefits should be subtracted in the calculation of damages. In their setting, off-setting benefits occur when, for instance, the victim of an accident can derive income from writing a book on the ordeals, or when the accident causes the victim to change into a higher-earning career. They provide reasons to be cautious in subtracting such benefits, but it is a premise of their analysis that such benefits should, in principle, be subtracted in order to ensure optimal internalization. This premise holds in the context which they consider of only one injurer, but may not hold when the offsetting benefits are caused by the injurers' negligent acts in the context of two or more injurers, as we will show below.

We now illustrate our main results in two simple examples.

[13] We do not show it, but there exists an inefficient equilibrium also under strict liability.

[14] Comprehensive Environmental Response, Compensation, and Liability Act, known also as Superfund.

[15] This is also reflected in Tietenberg's (1989) analysis of joint and several liability in the context of toxic torts.

[16] He mentions for instance United States v. Alcan Aluminum Corp.), 49 F. Supp. 2d 96 (N.D.N.Y 1999).

[17] Part of Grady's analysis concerns the case where parties may lapse; this is not part of our analysis, though it is clearly relevant.

[18] Grady considers the sequential case where one injurer dumps waste after another, but our compensation principle applies also to that case when the standard of negligence is invariant, i.e. when the second injurer's standard of due care is not affected by the amount of the first injurer's dumping.

4. Two examples

The first example involves two injurers and one harmed good, while the second example involves two injurers and more than one harmed good.

Consider two injurers, *A* and *B*, who may pollute a river containing fish owned by *C*.

	B emits	B does not emit(due care)
A emits	100 dead fish	70 dead fish
A does not emit (due care)	70 dead fish	0

In this first example, we consider fish as one good, each worth one unit of account. It costs either party 49 units to prevent pollution. It is efficient that neither *A* nor *B* pollutes, since 70 > 49, and 100 > 98. But-for-negligence causation implies that the parties' liabilities, d_A and d_B, cannot each exceed $100 - 70 = 30$. Hence, $d_A + d_B$ will be at most 60, which means that total liability will fall short of the total loss of 100, which arises when both are negligent. In this example, it is important that liabilities sum to at least 98 for if not it will be optimal for at least one party to pollute.

This is an instance of the compensation principle to which we shall return below. It essentially implies that if liabilities sum to total harm, the Nash equilibrium must be efficient. In other words, if the sum of maximal liabilities, i.e. the sum of the two injurers' but-for-negligence causation, is below 100, there will exist costs of care that lead to an inefficient Nash equilibrium (such that the parties should efficiently take care but do not).

We consider it a contribution of this paper to link this compensation principle with the topic of causation. Thus, in the example, the Nash equilibrium is inefficient under but-for-negligence causation, and this is due to the existence of multiple (or more exactly, duplicate) sufficient causation. Both parties sufficiently cause 70 which is why total liabilities do not sum to more than 30. From this it can be seen if the 70, the harm duplicately caused, were seen to be caused by the parties, e.g. shared between them in the calculation of liability, the sum of liabilities would sum to total harm of 100, and so incentives would be optimal according to the compensation principle. Hence, when there are only two injurers and only one good (no offsetting benefit) it is enough to consider multiple sufficient causation as part of causation for incentives to be correct under the but-for-negligence rule.

The second example of two injurers and more than one good is a slightly altered version of the first:

	B emits	B does not emit(due care)
A emits	100 dead Z-fish	70 dead A-fish
A does not emit (due care)	70 dead B-fish	0

We now distinguish different kinds of fish, though we assume for simplicity that the three different kinds are equally valuable (each worth one unit). One can imagine that the chemicals emitted by the two injurers counteract each other for some kinds of fish (A- and B-fish) but kill Z-fish when emitted together. In this example, a distinction must be made between injury in terms of goods and harm in terms of value.

If one applies but-for-negligence causation in terms of value, neither injurer is liable for more than 30. Incentives are then insufficient, as above. One potential solution is to ignore the offsetting benefit in the calculation of but-for-negligence causation, or, equivalently, to apply but-for-negligence causation in terms of the actual injury to the Z-fish; this latter injury is caused by both firms such that but-for-negligence causation amounts to the full harm for both parties.

Under either solution, incentives will be efficient according to the compensation principle, but liabilities will be unaffected by the harm that occurs when only one of the injurers is negligent. We believe this might be undesirable. If, for instance, *A* on his own would have harmed 100 A-fish such that *B*'s negligence was beneficial (much like in nurse's negligence in the example mentioned in the introduction), it would seem important to provide strong incentives for *A* to take due care (given that *B* might err). We discuss this further below, after having introduced and analyzed the model.

5. The model

A single victim faces two injurers $i = A, B$ who choose (precautionary) actions x_i from the set X_i of available alternatives at cost $c_i(x_i)$. These sets may contain more than two alternatives and they need not be linearly ordered. This allows us to think of general precaution measures instead of mere precaution levels or expenditures.

As a third but otherwise passive party, the victim is affected by the action profile $x = (x_A, x_B)$ chosen by *A* and *B* from $X = X_A \times X_B$. Let $H(x)$ denote injury in physical terms as a function of the action profile *x*. More precisely, think of *G* as the set of all (discrete) physical goods possibly being destroyed. By definition, the injury $H(x)$ is the subset of *G* consisting of those goods that are lost at action profile *x*.

Two things are particularly worth noting with regard to this definition of the consequences of the acts of the two injurers. First, we have in mind that the two injurers by their acts change a status quo, defined as what would be the state of nature in the absence of the acts. Note that the status quo might change even if the injurers both act with due care; there may hence be injury even if the injurers both act with due care. Second, one might formulate the consequences of the injurers' acts not only in terms of goods lost but also in terms of goods gained. However, we shall economize on notation by only considering goods lost and then consider gains as goods that might have been lost in the status quo or in some other hypothetical state, but which, as a consequence of acts undertaken by the injurers, are not lost.

The consequences of the injurers acts can also be expressed in value terms, i.e. as losses, rather than in terms of the injury to physical goods. The translation from injury to monetary loss is straightforward: Each good in *G* has a price and, for any subset *g* of *G*, its monetary value $m(g)$ is equal to the sum of prices of the goods in it. With this notation, let $h(x) = m[H(x)]$ denote the value of the goods $H(x)$ lost at action profile *x*. This function $h(x)$ is referred to as the harm function. From this function, we define the standards of due care $x^* = (x_A^*, x_B^*)$ as those acts which minimize social costs $s(x) = c_A(x_A) + c_B(x_B) + h(x)$ over all *x*. As the injurer may choose excessive precaution, we assume that an act is only negligent if it leads to greater harm for the victim than the efficient act would have. I.e. when *j* has chosen x_j, *i* is only negligent when $h(x_i, x_j) > h(x_i^*, x_j)$.

We are now able to define rules concerning the apportionment or damages. A damages rule ascribes damages $d(x) = (d_A(x), d_B(x))$ for each injurer given their acts $x = (x_A, x_B)$. The negligence requirement and the causation requirement each puts restrictions on the damages rule. The negligence requirement is that $d_i(x_i^*, x_j) = 0$ for all x_j. causation requirement stipulates that when *i* is considered the cause of harm equal to $\lambda_i(x)$, it must be the case that $d_i(x) = \lambda_i(x)$. As the causation requirement is in fact an upper constraint on damages we could instead have formulated it as $d_i(x) \leq \lambda_i(x)$, but since we analyze the extent to which a causation principle restricts incentives, we assume that damages are maximal under the principle. The question to be analyzed is whether a damages rule that fulfills both requirements ensures efficiency.[19]

[19] Note that we do not formulate a third restriction on the damages rule, namely that there must not be enrichment of the victim. In reality, this is a restriction that courts sometimes do impose, especially in civil law countries. However, there is no need for us to burden the analysis with this restriction, as our point will be that the

We now consider how $\lambda_i(x)$ is determined by the rule of but-for-negligence causation. We can begin by considering the injury (and the offsetting benefits) in the goods space. Fundamentally, injurer i's deviation $x_i \neq x_i^*$ is the but-for-negligence cause of injury $H_i(x_i, x_j) = H(x_i, x_j) \backslash H(x_i^*, x_j)$ which consists of those goods that have been destroyed at actual profile $x = (x_i, x_j)$ but would have been saved, if i had not deviated. At the same time, there may be offsetting benefits, namely the set $O_i(x_i, x_j) = H(x_i^*, x_j) \backslash H(x_i, x_j)$, which are those goods that at actual profile (x_i, x_j) have not been lost but would have been, had i not deviated. Injurer i's deviation is the but-for-negligence cause of these purely hypothetical off-setting benefits. From this description of but-for-negligence causation in the goods space, the causation restriction on the damages rule in value terms follows naturally. Thus, the value of the first mentioned injury equals $m\left[H_i(x_i, x_j)\right] = m\left[H(x_i, x_j) \backslash H(x_i^*, x_j)\right]$, from which must be subtracted the value of the off-setting benefit, $m\left[O_i(x_i, x_j)\right]$. Hence, causation in value terms amounts to $m\left[H_i(x_i, x_j)\right] - m\left[O_i(x_i, x_j)\right]$ which amounts to $\left[h(x_i, x_j) - h(x_i^*, x_j)\right]$.[20]

Recall our assumption that if the injurer's act benefits the victim, the act is not negligent. This implies that injurer i's liability cannot exceed $\Delta_i(x_i, x_j) = \max\left[h(x_i, x_j) - h(x_i^*, x_j), 0\right]$ and so but-for-negligence causation implies that $\lambda_i(x) = \Delta_i(x_i, x_j)$.

We say that the damages rule is compensatory at action profile x when the victim is not worse off after damages, i.e. when

$$d_A(x) + d_B(x) \geq \Delta(x) = \max\left[h(x) - h(x^*), 0\right]$$

is satisfied. It is called compensatory when it is compensatory everywhere.

For illustration, we sometimes look at one-dimensional choice sets where X_i is a subset of the real numbers and where the harm function $h(x)$ is monotonically increasing. In this case, the harm function $h(x)$ is called sub-modular if it increases less by an increase in one argument when the other argument is higher (see, e.g. Milgrom and Roberts, 1990, p. 516). In particular, for $x_A^* < x_A$ and $x_B^* < x_B$, this means that $h(x_A, x_B) - h(x_A^*, x_B) < h(x_A, x_B^*) - h(x_A^*, x_B^*)$ must hold. When the harm function is sub-modular then the damages rule subject to but-for-negligence causation cannot be compensatory at $x = (x_A, x_B)$ for which $x_i^* < x_i$ is true for both injurers $i = A, B$.

In fact, when the harm function is sub-modular then

$$\begin{aligned}\Delta(x) = \; & h(x) - h(x^*) = h(x) - h(x_A^*, x_B) + h(x_A^*, x_B) - h(x^*) > \\ & > h(x) - h(x_A^*, x_B) + h(x_A, x_B) - h(x_A, x_B^*) = \Delta_A(x) + \Delta_B(x)\end{aligned}$$

and, indeed, this rule is not compensatory at any profile (x_A, x_B) with $x_A^* < x_A$ and $x_B^* < x_B$.

The harm function is called super-modular if it increases more by an increase in one argument when the other argument is higher. In this case, $\Delta(x) \leq \Delta_A(x) + \Delta_B(x)$ holds for any action profile $x = (x_A, x_B)$ as is now shown. If $x_A^* < x_A$ and $x_B^* < x_B$ then the claim follows by an argument that is symmetric to the one above. If, however, $x_A \leq x_A^*$ but $x_B^* < x_B$ then $\Delta_A(x_A, x_B) = 0$ and, hence, $\Delta(x) \leq \Delta_B(x) = \Delta_A(x) + \Delta_B(x)$ because $h(x_A, x_B^*) \leq h(x_A^*, x_B^*)$ as follows from the monotonicity of the harm function. Therefore the claim must hold for such profiles as well. The remaining cases can be handled analogously. It then follows that if the harm-function is super-modular then the but-for-negligence rule is compensatory everywhere.

Finally, it might be worth being pointed out that when the harm function is differentiable then it is increasing if $\partial h(x)/\partial x_i > 0$ holds for $i = A, B$ and it is sub-modular if $\partial^2 h(x)/\partial x_A \partial x_B < 0$, whereas it is super-modular if $\partial^2 h(x)/\partial x_A \partial x_B > 0$ is satisfied at all profiles x.

6. Compensation and efficiency

We now show three results that tie the victim's compensation to efficiency.

Lemma 1. *(i) When a negligence rule is subject to but-for-negligence causation then it is compensatory at unilateral deviations.*

(ii) When a negligence rule is compensatory at unilateral deviations then the efficient profile is a Nash equilibrium.

Proof. To establish claim (i), consider a unilateral deviation (x_i, x_j^*) by injurer i. Since $d_j(x_j^*, x_i) = 0$, by the definition of a negligence rule, and since $d_i(x_i, x_j^*) = \Delta_i(x_i, x_j^*)$ under but-for-negligence causation, it follows that

$$d_i(x_i, x_j^*) + d_j(x_j^*, x_i) = \Delta_i(x_i, x_j^*) = \Delta(x_i, x_j^*)$$

and, indeed, this rule is compensatory at any unilateral deviation (x_i, x_j^*).

It remains to establish claim (ii). Since the negligence rule is compensatory at unilateral deviations (x_i, x_j^*) by i it follows that

$$d_i(x_i, x_j^*) + d_j(x_i, x_j^*) = d_i(x_i, x_j^*) \geq \Delta(x_i, x_j^*)$$

and, hence, that

$$\begin{aligned}& c_i(x_i) + d_i(x_i, x_j^*) \geq c_i(x_i) + \Delta(x_i, x_j^*) \geq c_i(x_i) + h(x_i, x_j^*) - h(x^*) = \\ & = s(x_i, x_j^*) - c_j(x_j^*) - h(x^*) \geq s(x^*) - c_j(x^*) - h(x^*) = c_i(x_i^*)\end{aligned}$$

and so x_i^* is a best response by injurer i to the efficient choice x_j^* of the other party. As this is true for both parties $i = A, B$, the efficient profile consists of mutually best responses and, hence, it is indeed a Nash equilibrium. This establishes claim (ii). □

This lemma confirms Shavell's analysis (Shavell, 1980). As a second result we show that if a negligence rule is compensatory at every profile x then Nash equilibria must be efficient. This latter result we shall denote the compensation principle, as derived in Schweizer (2017) and applied in Schweizer (2020):

Lemma 2. *Suppose the negligence rule $d(x)$ is compensatory everywhere. Then:*

(i) *The efficient profile x^* is a Nash equilibrium.*
(ii) *If x^N is any other Nash equilibrium then x^N must also be efficient.*

Proof. (i) It follows from Lemma 1 that the efficient profile must be a Nash equilibrium.

(ii) Recall that social costs amount to $s(x) = c_A(x_A) + c_B(x_B) + h(x)$. As x^N is a Nash equilibrium, in particular, $c_i(x_i^N) + d_i(x^N) \leq c_i(x_i^*) + d_i(x_i^*, x_j^N) = c_i(x_i^*)$ must hold for $i = A, B$. Moreover, since $d_A(x^N) + d_B(x^N) \geq \Delta(x^N)$ (by assumption, the rule is compensatory at any x and, in particular, at x^N), it follows that

$$\begin{aligned}s(x^N) &= c_A(x_A^N) + c_B(x_B^N) + h(x^N) \\ &\leq c_A(x_A^*) + c_B(x_B^*) + h(x^N) - d_A(x^N) - d_B(x^N) \\ &\leq c_A(x_A^*) + c_B(x_B^*) + h(x^N) - \Delta(x^N) \leq c_A(x_A^*) \\ &+ c_B(x_B^*) + h(x^*) = s(x^*)\end{aligned}$$

causation requirement may in itself prevent efficiency also in the absence of the no-enrichment rule.

[20] Note that the benefits might not be hypothetical if the victim obtains some positive benefit from an injurer's negligence; we have excluded this possibility in our formulation by assuming that the victim suffers only losses. It should be clear that not subtracting such benefits is equivalent to not subtracting avoided harm.

$$
\begin{aligned}
s(x^N) &= c_A(x_A^N) + c_B(x_B^N) + h(x^N) \\
&\leq c_A(x_A^*) + c_B(x_B^*) + h(x^N) - d_A(x^N) - d_B(x^N) \\
&\leq c_A(x_A^*) + c_B(x_B^*) + h(x^N) - \Delta(x^N) \leq c_A(x_A^*) \\
&+ c_B(x_B^*) + h(x^*) = s(x^*)
\end{aligned}
$$

must hold. As x^* minimizes social costs, the above inequalities must be binding and, in particular, $s(x^N) = s(x^*)$ must be true, i.e. any Nash equilibrium is indeed efficient. □

We denote a negligence rule efficient when it satisfies (i) and (ii) of Lemma 2. It then follows from the compensation principle that compensatory negligence rules are efficient. We note that the compensation principle also holds for more than two injurers as every step of the proof holds for any number of injurers. It even holds for settings where the victim is an acting party as shown in Section 9.

The two lemmas do not tell us whether there can be an inefficient Nash equilibrium when the damages rule is not compensatory everywhere. We now show that while a non-compensatory damages rule does not necessarily lead to inefficiency, it can do so in the sense that there exist cost-functions for which there will be an inefficient Nash equilibrium.

Lemma 3. *If a negligence rule is not compensatory at an action profile x^N then there exist cost functions such that x^N is an inefficient Nash equilibrium.*

Proof. For a given harm function $h(x)$, consider any two action profiles x^N and x^* with x_i^* different from x_i^N for $i = 1, 2$. The damages rule $(d_A(x), d_B(x))$ is a negligence rule and so $d_i(x_i^*, x_j) = 0$ is assumed to hold for $i = A, B$ and for all unilateral deviations x_j from x_j^* by the other injurer. By assumption, the damages rule is not compensatory at x^N and so

$$d_A(x^N) + d_B(x^N) < \Delta(x^N) = \max\left[h(x^N) - h(x^*), 0\right]$$

must hold.because the damages rule is not compensatory at x^N.is satisfied. For these cost functions, x^* is the efficient action profile. While party i is indifferent between x_i^N and x_i^*, the profile x^N is a Nash equilibrium nonetheless. To break indifference, we may lower $c_i(x_i)$ by a sufficiently small amount so that x^N remains inefficient. □

The above results extend findings by Jain and Kundu (2006) to our more general model. These authors consider one-dimensional precaution choice and examine what they call simple liability rules. Such rules depend exclusively on the zero-one profile of who is negligent and who is not. A simple liability rule is called efficient if a Nash equilibrium exists for all applications[21] and if all these Nash equilibria are efficient. Efficient simple liability rules can be characterized by the condition CNL of collective negligence liability (only negligent actors are liable and harm is fully covered). In our terminology, this means that simple liability rule satisfying condition CNL are particular instances of compensatory negligence rules and, hence, our compensation principle (Lemma 2) applies to these rules. Lemma 3 is a substitute for the requirement of Jain and Kundu that the simple liability rule must be efficient for all applications.

Returning to our more general framework, we can now show the following result when the choice of precaution is one-dimensional.

Proposition 1. *Under the but-for-negligence rule of causation, a negligence rule may be inefficient when the harm-function is sub-modular but it is efficient when the harm-function is super-modular.*

[21] For the notion of an application, the reader should consult Jain and Kundu directly.

Proof. Consider any profile x^N with $x_i^* < x_i^N$ for $i = A, B$. If the harm function is sub-modular then $\Delta_A(x^N) + \Delta_B(x^N) < \Delta(x^N)$ as has been shown in the previous section. Therefore, at such a profile x^N, the but-for-negligence rule of causation cannot be compensatory and the claim follows from Lemma 3.

If, however, the harm function is super-modular then, as has already been shown in the previous section, but-for-negligence causation is compensatory everywhere and the claim follows from the compensation principle. □

The next result is more general, as it holds beyond one-dimensional choice sets. Let $H^d(x) = H(x) \cap H(x_A^*, x_B) \cap H(x_A, x_B^*)$ denote the set of duplicately caused injury, i.e. any good $g \in H^d(x)$ is lost at x but would also have been lost when only one of the parties had been negligent. Recall that $O_i(x) = H(x_i^*, x_j) \backslash H(x_i, x_j)$ denotes the set of offsetting benefits. We can then show:

Proposition 2. *Suppose there are two injurers. Then:*

(i) If the injurers share liability for duplicately caused injury and if offsetting benefits are not deducted, then negligence rules that satisfy but-for-negligence causation are efficient.

(ii) If, at any action profile x, there are neither duplicately caused injuries nor offsetting benefits then negligence rules that satisfy but-for-negligence causation are efficient.

Proof. It is generally true that $H(x) = H_A(x) \cup H_B(x) \cup H^d(x)$ and, hence, the inequality

$$\Delta(x) \leq h(x) = m\left[H(x)\right] \leq m\left[H_A(x)\right] + m\left[H_B(x)\right] + m\left[H^d(x)\right]$$

holds for all x. Therefore, if injurer i is liable for $m\left[H_i(x)\right]$ because offsetting benefits are not deducted and if the two injurers share liability for $m\left[H^d(x)\right]$, the damages regime (i) is compensatory and claim (i) follows from the compensation principle.

$$\Delta(x) \leq h(x) \leq m\left[H_A(x)\right] + m\left[H_B(x)\right] = \Delta_A(x) + \Delta_B(x)$$

holds indeed for all x when duplicately caused harm and offsetting benefits can be ruled out. Claim (ii) then follows from the compensation principle. □

To summarize: In the case of two injurers inefficiency can come about only through duplicate causation or offsetting benefits; in their absence, but-for-negligence causation ensures efficiency. And efficiency can also be ensured if one counts duplicate causation as causation while neglecting offsetting benefits.

What has just been said about the but-for-negligence rule applies of course also to more expansive notions of causation, such as the but-for-activity rule and cost-benefit rule advocated by Grady and mentioned in footnote (8) above.

7. Divisibility

We now address the consequences of limited measurability or divisibility. For illustration, we look at one-dimensional action choice $x = (x_A, x_B)$ and we assume that $0 < x_i^* < x_i$. We noted above that when it is difficult for the defendant or the fact-finder to obtain information regarding what the level of harm would have been if an injurer had acted with due care the court may fall back on either the but-for-activity rule by which injurer i can be held liable for the difference $h(x_i, x_j) - h(0, x_j)$ between the actual harm and the harm that would have occurred if he or she had not participated in the activity or on a rule of joint liability for jointly caused harm by which each injurer can be held liable for the difference $h(x_i, x_j) - h(x_i^*, x_j^*)$ between the actual harm and the harm that would have occurred if neither of them had acted negligently. It turns out that the consequences of either of these two possibilities are easy to analyze using our previous results.

First, it is clear that the but-for-activity rule does not ensure efficiency. To see why assume that the harm function is sub-modular.

Recall that, in this case, $\Delta_A(x)+\Delta_B(x)<\Delta(x)$ holds for all x with $x_i^* < x_i$ for $i=A, B$ and so but-for-negligence causation is not compensatory at any such profile x. While but-for-activity causation increases liability because $h(x_i, x_j) - h(x_i^*, x_j) < h(x_i, x_j) - h(0, x_j)$, it is easy to find examples where, nonetheless,

$$[h(x_A, x_B) - h(0, x_B)] + [h(x_A, x_B) - h(x_A, 0)] < \Delta(x)$$

would still be satisfied. It then follows from lemma 3 that but-for-activity causation need not be efficient as it may allow for an inefficient Nash equilibrium.

Second, it is clear from the compensation principle that if the injurers share liability for the harm that they have jointly caused, there can only exist efficient Nash equilibria, as there is then full compensation of the victim.

8. Alternative notions of causation

In this section, we deal with causation based on the Shapley value and compare it with the NESS-test. We do so for any number $I=\{1, \ldots, n\}$ of injurers. An action profile $x=(\ldots, x_i, \ldots) \in X=X_1 \times \cdots \times X_N$ now lists a precautionary action $x_i \in X_i$ for any injurer $i \in I$. It costs $c_i(x_i)$ for i to choose x_i.

To make use of the Shapley value, we must specify a characteristic function that assigns a numerical value $v(x, S)$ to any coalition $S \subset I$ of injurers. In our application, this value depends on the chosen action profile x. We will make use of the characteristic function $v(x, S) = h(x_S, x^*_{-S}) - h(x^*)$ and so we may say that the deviation x_S by coalition S is the sufficient but-for-negligence cause of harm $h(x_S, x^*_{-S}) - h(x^*)$.

Consider a coalition S that does not contain i. Then the marginal contribution of i's negligence to the harm sufficiently caused by coalition $S\cup\{i\}$ amounts to

$$v(x, S\cup\{i\}) - v(x, S) = h(x_i, x_S, x^*_{-S}) - h(x_i^*, x_S, x^*_{-S}).$$

The Shapley value assigns to i the weighted average

$$S_i(x) = \sum_{S\subset I, i\notin S} \alpha_i(s)\cdot [v(x, S\cup\{i\}) - v(x, S)]$$

of i's marginal contributions with Shapley weights $a_i(s) = \frac{(n-1-s)!s!}{n!}$. Here s denotes the number of injurers in S.

When there are offsetting benefits, the Shapley value may attain negative values. Since we have assumed liability to be non-negative, we define liability apportioned according to the Shapley value by $\lambda_i(x) = \max[S_i(x), 0]$. Note that $S_i(x_i^*, x_{-i}) = 0$ for any deviation by the other injurers and, hence, the rule $d_i(x) = \lambda_i(x)$ is a negligence rule. Before showing that it is compensatory, the following example may serve as illustration of the Shapley value.

First, if S is empty, then the marginal contribution by i amounts to $h(x_i, x^*_{-i}) - h(x^*)$.[22] It is the harm for which i's deviation x_i from x_i^* was a sufficient cause. Second, if $S\cup\{i\} = I$ then the marginal contribution of i amounts to $h(x_i, x_{-i}) - h(x_i^*, x_{-i})$. It is the harm for which i's deviation x_i from x_i^* was a necessary cause. Therefore, if there are just two injurers then the Shapley weights are $\alpha(0) = \alpha(1) = 1/2$ and, hence, Shapley causation assigns the average of the two marginal contributions, i.e. the average of necessarily and sufficiently caused harm.

For any number of injurers, we can now show that:

Proposition 3. *Damages $d_i(x) = \max[S_i(x), 0]$ apportioned according to the Shapley value are a negligence rule that is compensatory and hence efficient.*

[22] For notational simplicity, we assume that $h(x^*) = 0$ holds in this example.

Proof. For any characteristic function, it is true that the individual Shapley values add up to the value of the grand coalition, in our case, $\sum_{i\in I} S_i(x) = v(x, I) = h(x) - h(x^*)$ and, hence,

$$\sum_{i\in I} d_i(x) = \sum_{i\in I} \max[S_i(x), 0] \geq \Delta(x) = \max[h(x) - h(x^*), 0]$$

holds for all action profiles x. Therefore damages $d_i(x)$ apportioned according to the Shapley value are compensatory at any action profile x. It then follows from the compensation principle that these damages are efficient. □

As mentioned, the NESS-test holds an injurer liable for an actually suffered injury when the injurer is a member of a coalition $S\cup\{i\}$ whose negligent acts are sufficient for the injury and when the injurer's negligence is necessary for that sufficiency. In other words, an injurer i is liable for the loss of some good $g \in H(x)$, if there exists a coalition S not containing i so that the marginal contribution of i's negligence to the harm sufficiently caused by the coalition $S\cup\{i\}$ includes the good g, i.e. if $g \in H(x_i, x_S, x^*_{-S}) \backslash H(x_i^*, x_S, x^*_{-S})$.

The NESS test may hold more than one injurer liable for the loss of one and the same good. However, the following result shows, for any good $g \in H(x)\setminus H(x^*)$ that is lost given action profile x, at least one injurer exists that is liable for its loss. This means that the victim can recover all of $H(x)\setminus H(x^*)$ and so the compensation principle applies.

Proposition 4. *Suppose that the victim can recover any good, for which at least one injurer is liable according to the NESS-test. Then such a damages regime is compensatory and, hence, efficient.*

Proof. Note that

$$H(x) \subset \bigcup_{i=1}^{I} \{H(x_1^*, \ldots, x_{i-1}^*, x_i, \ldots, x_I) \backslash H(x_1^*, \ldots, x_{i-1}^*, x_i^*, x_{i+1}, \ldots, x_I)\} \cup H(x^*)$$

holds at any action profile x. Moreover, under the NESS-test, injurer k is liable for the loss of goods from the set

$$H(x_1^*, \ldots, x_{i-1}^*, x_i, \ldots, x_I) \backslash H(x_1^*, \ldots, x_{i-1}^*, x_i^*, x_{i+1}, \ldots, x_I)$$

because, within the coalition $S\cup\{i\} = \{i\}\cup\{i+1, \ldots, I\}$, the deviation x_i by i is necessary for the loss of such goods. It follows that the victim recovers any g from the set $H(x)\setminus H(x^*)$. This regime is compensatory and, hence, efficient as follows from the compensation principle. □

We shall not make a full comparison between the Shapley value and the NESS-test but note three significant differences.

First, as mentioned in the introduction, while the Shapley value considers harm in value terms, the NESS-test considers injury in physical terms and in such a manner that offsetting benefits are not deducted. That this makes a difference can be illustrated in the example of the doctor and the nurse. Let us assume that the loss of life equals 10 while the loss of health equals 1 in monetary terms. As the Shapley value attributes the average of marginal harm and sufficient harm in value terms to each injurer, the doctor is liable for $1/2\cdot 10 + 1/2\cdot 0 = 5$, while the nurse is liable for $1/2\cdot(-9) + 1/2\cdot 1 = -4$, summing up to the total loss of 1. Since total liability is not greater than 1, the doctor would be liable for a loss of 1 and the nurse for zero.

By contrast, under the NESS-test, the actual injury of lost health is caused whenever the nurse acts negligently. There are hence two coalitions that are sufficient for the victim's actual harm, namely (nurse, doctor) and (nurse). If in the coalition (doctor, nurse), the doctor had acted with due care, the injury would still have occurred, so the doctor is not liable at all under the NESS-test. By contrast, if the nurse had acted with due care, the actual harm would not have occurred (as the victim would have died). Therefore, the nurse is liable for the full harm to the victim. We conclude that in this exam-

ple the Shapley value and the NESS-test lead to opposite outcomes, in part because only the Shapley value considers offsetting benefits.

Second, as pointed out by Ferey and Dehez (2016), the NESS-test cannot ascribe degrees of causation in scenarios where some injurers can be said to have contributed more to an accident than others but where every injurer's negligent act is a necessary element in a sufficient set. As argued more generally by Braham and Van Hees (2009), it may be desirable to speak of degrees of causation rather than to think of causation as a dichotomy.

Third, the Shapley value fulfills desirable fairness axioms. As noted by Ferey and Dehez (2013, p. 152), if we require that the victim is fully compensated (termed efficiency in cooperative game theory), that different players who contribute to harm in the same way are treated the same (symmetry), and that only marginal contributions to harm matters for the apportionment of causation, must be allocated by the Shapley value. Remarkably, as shown by Shapley (1953), the Shapley value is also the single solution that fulfills the requirements of linearity (if several goods are harmed in an accident we can find a person's causation by calculating the Shapley values for each good and then adding them up), the requirement of symmetry as defined above, and the requirement that a null player not contributing to harm is attributed no causation.

9. The victim as an active party

So far, the victim has been assumed to be passive. In this section, we extend our model to a setting where the victim must also take a decision y from the set Y of available alternatives. An action profile $(x, y) = (x_1, \ldots, x_n, y) \in X_1 \times \cdots \times X_N \times Y = X \times Y$ now lists a precautionary action $x_i \in X_i$ for any injurer $i \in I$ as well as an action $y \in Y$ of the victim. It costs $c_i(x_i)$ for injurer i to choose x_i and $c_V(y)$ for the victim to choose y. Harm (in monetary terms) $h(x, y)$ is a function of the entire action profile. The standards of care (x^*, y^*) are defined as those acts which minimize social costs $s(x, y) = c_V(y) + \sum_{i \in I} c_i(x_i) + h(x, y)$ over all action profiles (x, y). The profile (x^*, y^*) is referred to as the efficient one. Let $d_i(x, y)$ denote damages owed by injurer i to the victim as a function of the action profile (x, y). The negligence requirement is that $d_i(x_i^*, x_{-i}, y) = 0$ holds for all actions x_{-i} by the other injurers and any action y of the victim. In the context of a passive victim we defined a compensatory negligence rule as one that makes the victim whole when one or more injurers act negligently. We now extend the concept to an active victim by saying that a negligence rule is compensatory when the victim is fully compensated when the victim acts with due care. Thus, the compensation requirement is satisfied provided that $c_V(y^*) + h(x, y^*) - \sum_{i \in I} d_i(x, y^*) \leq c_V(y^*) + h(x^*, y^*)$ and, hence,

$$h(x, y^*) - h(x^*, y^*) \leq \sum_{i \in I} d_i(x, y^*)$$

holds for all deviations x by the injurers. The following result is an extension of lemma 2 to the setting with the victim as an active party.

Lemma 4. *Suppose the negligence rule $d_i(x, y)$ is compensatory in the above sense. Then:*

(i) *The efficient profile (x^*, y^*) is a Nash equilibrium.*
(ii) *If (x^N, y^N) is any Nash equilibrium then (x^N, y^N) must also be efficient.*

The proof is omitted because it can easily be adapted from that of lemma 2. As an application, let us compare the case with one injurer and one active victim with that of two injurers and one passive victim. In the former case, the victim must be fully compensated when only the injurer acts negligently as follows from the but-for-negligence rule. In the latter case, we know from the analysis above that inefficiency can arise when the harm-function is submodular. This means that it is not correct when citealandes1980jointLandes and Posner (1980, p. 518) claim that the case of two injurers and a passive victim is analytically the same as the one between an injurer and an active victim.

This should be kept in mind when analyzing instances of multiple sufficient causation where the victim sufficiently causes the loss, e.g. by not reading an incomplete manual. In this instance, incentives are efficient even when the injurer is not held liable, since the victim then bears the full loss.[23]

Next, it is shown how the Shapley value can be extended to the setting with an active victim. The set of agents is now $I^+ = I \cup \{V\}$. It consists of all tortfeasors and the victim. A coalition S is a subset of I^+ that may but need not include the victim. For a coalition $S \subset I^+$, of which the victim is not a member, the characteristic function is defined as $v(x, y, S) = h(x_S, y^*, x^*_{-S}) - h(x^*, y^*)$ whereas, for a coalition $S = S' \cup \{V\}$ including the victim, the characteristic function is defined as $v(x, y, S) = h(x_{S'}, y, x^*_{-S'}) - h(x^*, y^*)$. The Shapley value assigns to any party $i \in I^+$ the weighted average

$$S_i(x, y) = \sum_{S \subset I^+, i \notin S} \alpha_i(s) \cdot [v(x, y, S \cup \{i\}) - v(x, y, S)] .$$

For party $i \in I^+$, the weights are now defined as $\alpha_i(s) = \frac{(n-s)!s!}{(n+1)!}$ where s is the number of members in S because the grand coalition I^+ has now $n+1$ members.

Suppose damages owed by injurer $i \in I$ to the victim are defined as $d_i(x, y) = \max[S_i(x, y), 0]$. Then, for the same reason as in the model with a passive victim, these damages constitute a negligence rule. Moreover, since $S_V(x, y^*) = 0$ holds for any deviation x by the injurers and since the individual Shapley values add up to the value of the grand coalition, it follows that

$$\sum_{i \in I^+} S_i(x, y^*) = v(x, y^*, I^+) = h(x, y^*) - h(x^*, y^*)$$

must hold and, hence, the damages rule based on the Shapley value remains compensatory. It then follows from the above lemma that the efficient action profile is a Nash equilibrium and, if more than one Nash equilibrium exists, all must be efficient even if the victim is an active party.

As a final comment, Feldman and Singh (2009) have introduced what they call the super-symmetric rule to demonstrate that discontinuity in the liability share is not required for efficiency. If applied to their setting of continuous and one-dimensional precaution choice, the above rule d_{AB} and d_{BA} based on but-for-negligence causation provides an even more natural example of such a continuous liability rule and it works even for bilateral harm cases. While Feldman and Singh deal with a unilateral harm model, Singh (2004) allows for bilateral harm cases in a setting with one-dimensional precaution choice. His condition of efficiency is closely related to what we call compensatory negligence rules.

10. Comparison with precedent

We now compare court practice with our normative results. With regard to multiple sufficient causation, the Restatement (Third) states (§27):

> If multiple acts occur, each of which under §26 alone would have been a factual cause of the physical harm at the same time in the absence of the other acts, each act is regarded as a factual cause of the harm.

[23] Multiple sufficient causation may still appear when it is an installer who fails to read the manual, rather than the victim.

This rule reflects precedent to some extent. Thus, the principle of but-for causation has often been discarded by courts in cases of multiple sufficient causation, usually involving at most two injurers. In an early case, Cook v. Minneapolis, St. P. & S. Ste. M. Ry.,[24] two fires, one of negligent and one of unknown origin, destroyed a property. The court held that full liability should result if the defendant's fire had combined with one of 'responsible' (negligent) origin, but that no damages should be asserted if the second fire was of innocent origin. Of these two prescriptions, only the former has been heeded by courts, and then not consistently. It was followed in the case of Sanders v. American Body Armor and Equipment, Inc.[25], where the victim died from two bullet wounds, one to the abdomen and one to the chest, both of which would have been fatal on its own. Although the vest could not have prevented the wound to the abdomen, the victim's family prevailed on appeal against the producer of the defective bullet proof vest.

It was also followed in a number of other cases listed by Green and Williams (2005, p. 17), in which two sufficient negligent acts were both held to be causal.

Nevertheless, it was not followed in Saunders System Birmingham Co. v. Adams[26], where a driver leased a car with defective brakes from the defendant; the defective brakes would presumptively have caused the accident if the driver had attempted to use them, but the defendant was not considered the cause of the pedestrian's injury. Nor was the prescription followed in several failure to warn cases, described by Fischer (1992), where the victim (an installer or an end-user) did not read the incomplete product warnings.[27] Thus, American courts have often held an injurer liable when an injurer's negligence was 'a material and substantial element' in causing plaintiff's damage even when the other sufficient cause was not of negligent origin.[28] Our analysis lends support to the rule that an injurer should be liable for duplicate causation when the other sufficient cause was of negligent origin. Otherwise circumstances may arise where incentives will be inadequate, and we believe it would be advisable for courts to consistently employ a rule that works under all circumstances.

We note, however, that when the injurers act sequentially, the analysis can change, since it is sufficient and may lead to a more coherent set of rules, to hold the injurer who acts first liable. In general, an injurer's act is measured by the state of nature existing at the time of his or her act.

As for offsetting benefits, Porat and Posner (2014, p. 1166) describe court practice as messy. Yet, while courts are not entirely consistent with regard to the question of whether the benefits that a negligent act bestows on a victim should be off-set in the calculation of damages, subtraction seems to mainly occur when and only when the harm and the benefit concern the same interest. This, at least, was expressed in the Second Restatement (American Law Institute, 1979) §920[29] :

> When the defendant's tortious conduct has caused harm to the plaintiff or to his property and in so doing has conferred a special benefit to the interest of the plaintiff that was harmed, the value of the benefit conferred is considered in mitigation of damages, to the extent that this is equitable.

comment b. of which reads:

> Limitation to same interest. Damages resulting from an invasion of one interest are not diminished by showing that another interest has been benefited. . . Damages for pain and suffering are not diminished by showing that the earning capacity of the plaintiff has been increased by the defendant's act. . . Damages to a husband for loss of consortium are not diminished by the fact that the husband is no longer under the expense of supporting the wife

Our analysis concerns the kind of off-setting benefits that occur when two or more injurers counteract each other's negligence. We have not found any legal cases of such interactions. What our analysis suggests is that if such cases should arise, courts should be cautious in subtracting benefits, since doing so may lead to inefficient incentives.

As for legal precedent concerning divisibility of damages, courts have not rarely found damages to be indivisible, not only in the early days of CERCLA. For instance, in Landers v. East Texas Salt Water Disposal Co.,[30] two tortfeasors emitted different amounts of pollutants into a lake, thereby killing fish owned by the plaintiff. The court considered the damages to be indivisible and held the injurers to be jointly liable. Likewise, in Maddux vs. Donaldsson[31], it was deemed impossible to divide personal injury damages among negligent automobile drivers in a chain collision.[32] However, in other cases, courts have attempted to divide damages by using input-proxies such as the amounts of pollutants, their toxicity, the length of time of exposure to harm (in the case of successive torts), or in the case of product liability, market shares, see Boston (1995).

Our analysis suggests that if the divisibility problem leads essentially to joint liability for jointly caused harm (and hence to the absence of individual causation requirements), incentives will be correct. There is of course the drawback that it may lead to too much liability on injurers, who in fact contribute only little to harm, distorting their activity level or leading to unfair outcomes.[33] Since a policy of dividing total actual losses by causation according to input-proxies also leads to efficient incentives according to the compensation principle, such a policy therefore seems preferable whenever feasible.

11. Comments

As for limitations of our analysis, it should be kept in mind that it focused on how the requirement of causation affects incentives; we did not address why too expansive definitions of causation may be undesirable. A broader theory of the optimal rule of causation would include effects on activity choices, as in Deffains et al. (2016), and might also include considerations of fairness, implementability, and judgment-proofness.[34]

Moreover, we did not address the issue of equilibrium selection. When there are two equilibria, one efficient and one inefficient, the equilibrium in which both injurers act negligently is likely to be risk-dominated by the one where both act with due care, while the former may Pareto-dominate the latter. Experiments indicate that in such coordination games with strategic uncertainty, people change behavior over time when the game is repeated. In Van Huyck et al. (1990), for instance, a majority chose what in our context is the inefficient act in the first shot of the game,[35] and only

[24] The following account is based in part on Boston (1995).
[25] 652 So.2d 883, 884 (Fla. App. 1995).
[26] 117 So. 72 (Ala. 1928).
[27] Also, in the context of two medical doctors both failing to diagnose a patient's disease correctly, the doctor being the first to examine the patient has sometimes not been considered the cause of the patient's death, see, e.g. Brown (2017).
[28] A practice begun in Anderson v. Minneapolis, St. Paul & S. Ste. M. Ry.
[29] The issue is not addressed in the Restatement (Third), see Green and Williams (2005).
[30] 248 S.W.2d 731 (Tex. 1952).
[31] 362 Mich. 425 (1961).
[32] Even when impossible to divide damages among a pre-existing condition and a negligent act, courts have in some cases held the negligent actor fully liable; the leading case is here Newbury vs. Vogel, 362 Mich. 425 (1961).
[33] Our analysis does not address these costs of liability, see comments below.
[34] See Kornhauser and Revesz (1990).
[35] Interestingly, many chose acts that are not part of a Nash-equilibrium.

over time did behavior converge towards what is the efficient outcome in our setting. These findings suggest that inefficiency can occur in our setting.

Our model did not include the stochastic nature of many tort accidents. When accidents occur with only a small probability, the inefficient equilibrium may be eliminated if the risks are not highly correlated, since it may then be unlikely that the negligent acts of two injurers will at the same time produce an accident. In this respect, our model fits better within the context of, e.g. nuisance or contract law. Likewise, injurers may not always be aware of each other's existence and potential negligence. However, causation rules should preferably be consistent over a broad range of situations, including non-stochastic harm (often associated with nuisance law), highly correlated risks, and instances where the injurers realize the existence of the other injurers and the strategic interaction. Moreover, tort rules should arguably take into account the possibility of hidden collusion between the injurers, which is more of an issue when there exists a Nash equilibrium from which no injurer will wish to deviate. Naturally, if there is collusion, the court will hold the parties jointly liable, as it should, but collusion may not be detectable.

Finally, we have not analyzed the case of sequential choice, where one injurer acts before the other (and the other knows the choice of the former; if not, the choice can be treated as simultaneous). As mentioned, sequential choice raises the issue of whether standards of due care should vary for the second injurer, depending on the choice of the first. This is related to the question of when one injurer's act has become part of the state of nature which we expect an injurer to take into account, and when we can consider their choices game-theoretically as interdependent. We did not wish to address these complications in depth. We therefore also have not addressed the issue of preemptive causation (one injurer poisoning the victim, another injurer preempting causation by shooting the victim), although it is similar to that of multiple sufficient causation and can be analyzed in our framework.

12. Conclusion

We have shown that the principle of but-for causation can restrict damages (in tort, nuisance or contract law) to such an extent that there are circumstances in which no efficient Nash equilibrium exists under a negligence rule. In the case of two injurers this may occur not only when there is duplicate sufficient causation but also when there are off-setting benefits of a kind which has to our knowledge not been analyzed before. It occurs when one party's negligence lowers the impact of the other's, as when a nurse fails to deliver a drug wrongly prescribed a doctor. These limitations of the concept of but-for causation can in practice be mitigated by the courts if they consider duplicate causation as a form of causation, if they disregard off-setting benefits, or if they react to divisibility problems by loosening individual causation, e.g. by applying joint (solidary) liability. Our results hence indicate that modified applications of but-for-negligence causation are likely to do well under a broad set of circumstances involving two injurers, at least in the sense that the applications allow for optimal incentives for due care. However, this may not be so for more than two injurers, and we therefore considered two main alternative concepts of causation from the perspective of our framework. We showed that while the Shapley value and the NESS-test both achieve efficiency when injurers act simultaneously, there are significant differences between them. One is that the former is formulated in terms of the injury that has actually occurred and so does not consider offsetting benefits. Moreover, since the Shapley value also conforms to a set of intuitive axioms, our analysis indicates that it is a theoretically more satisfactory concept of causation than both but-for causation and the NESS-test.

Conflict of interest

None declared.

References

American Law Institute, 1979. Restatement (Second) of Torts. American Law Institute Publishers.
American Law Institute, 2009. Restatement (Third) of Torts: Liability for Physical and Emotional Harm. American Law Institute Publishers.
American Law Institute, 2000. Restatement (Third) of Torts: Apportionment of Liability. American Law Institute Publishers.
Ben-Shahar, O., 2009. Causation and foreseeability. Encycl. Law Econ. 1, 83–108.
Boston, G.W., 1995. Toxic apportionment: a causation and risk contribution model. Environ. Law 25, 549.
Braham, M., Van Hees, M., 2009. Degrees of causation. Erkenntnis 71 (3), 323–344.
Brown, G.E., 2017. Reconsidering the superseding cause defense in failure-to-diagnose cases. Vermont Law Rev. 42, 529.
Calabresi, G., 1975. Concerning cause and the law of torts: an essay for Harry Kalven, Jr. Univ. Chicago Law Rev. 43 (1), 69–108.
Carpenter, C.E., 1934. Concurrent causation. Univ. Pa. Law Rev. 83, 941.
Carvell, D., Currie, J., Macleod, W.B., 2012. Accidental death and the rule of joint and several liability. RAND J. Econ. 43 (1), 51–77.
Cooter, R., 1987. Torts as the union of liberty and efficiency: an essay on causation. Chicage-Kent Law Rev. 63, 523.
Deffains, B., Fluet, C., Ropaul, M., 2016. Causation and standards of proof from an economic perspective. Chicago-Kent Law Rev. 91, 527.
Dehez, P., Ferey, S., 2013. How to share joint liability: a cooperative game approach. Math. Soc. Sci. 66 (1), 44–50.
Dillbary, J.S., 2013. Tortfest. Univ. Chicago Law Rev., 953–1005.
Dillbary, J.S., 2016. Causation actually. Georgia Law Rev. 51, 1.
Feldman, A.M., Singh, R., 2009. Comparative vigilance. Am. Law Econ. Rev. 11 (1), 134–161.
Ferey, S., Dehez, P., 2016a. Multiple causation, apportionment, and the Shapley value. J. Legal Stud. 45 (2016), 143–171.
Ferey, S., Dehez, P., 2016b. Overdetermined causation cases, contribution and the Shapley value. Chicago-Kent Law Rev. 91, 637.
Fischer, D.A., 1992. Causation in fact in omission cases. Utah Law Rev., 1335.
Grady, M.F., 1983. A new positive economic theory of negligence. Yale Law J. 92 (5), 799–829.
Grady, M.F., 1990. Multiple tortfeasors and the economy of prevention. J. Legal Stud. 19 (S2), 653–678.
Green, M.D., Williams, W., 2005. The Intersection of Factual Causation and Damages, SSRN: https://ssrn.com/abstract=803664.
Hart, H.L.A., Honoré, T., 1985. Causation in the Law. OUP Oxford.
Hylton, K.N., 2013. Causation in tort law: a reconsideration. Res. Handb. Econ. Torts, 97–113.
Hylton, K.N., Lin, H., 2015. Negligence and two-sided causation. Eur. J. Law Econ., 393–411.
Jain, S.K., Kundu, R.P., 2006. Characterization of efficient simple liability rules with multiple tortfeasors. Int. Rev. Law Econ. 26 (3), 410–427.
Kahan, M., 1989. Causation and incentives to take care under the negligence rule. J. Legal Stud. 18 (2), 427–447.
Kornhauser, L.A., Revesz, R.L., 1989. Sharing damages among multiple tortfeasors. Yale Law J. 98 (5), 831–884.
Kornhauser, L.A., Revesz, R.L., 1990. Apportioning damages among potentially insolvent actors. J. Legal Stud. 19 (S2), 617–651.
Landes, W.M., Posner, R.A., 1980. Joint and multiple tortfeasors: an economic analysis. J. Legal Stud. 9 (3), 517–555.
Landes, W.M., Posner, R.A., 1983. Causation in tort law: an economic approach. J. Legal Stud. 12 (1), 109–134.
Miceli, T.J., Segerson, K., 1991. Joint liability in torts: marginal and infra-marginal efficiency. Int. Rev. Law Econ. 11 (3), 235–249.
Milgrom, P., Roberts, J., 1990. The economics of modern manufacturing: technology, strategy, and organization. Am. Econ. Rev., 511–528.
Parisi, F., Singh, R., 2010. The efficiency of comparative causation. Rev. Law Econ. 6 (2), 219–245.
Peczenik, A., 1979. Causes and Damages. Juridiska föreningen.
Porat, A., Posner, E.A., 2014. Offsetting benefits. Virginia Law Rev. 100, 1165.
Robertson, D.W., 2009. Causation in the Restatement (Third) of torts: three arguable mistakes. Wake Forest Law Rev. 44, 1007.
Schweizer, U., 2017. Efficient compensation: lessons from civil liability. J. Inst. Theoret. Econ. 173 (1), 54–70.
Schweizer, U., 2020. But-for causation and the implementability of compensatory damages rules. J. Law Econ. Organ. 36 (2), 231–254.
Shapley, L.S., 1953. A value for n-person games. Contrib. Theory Games 2 (28), 307–317.
Shavell, S., 1980. An analysis of causation and the scope of liability in the law of torts. J. Legal Stud. 9 (3), 463–516.

Singh, R., 2004. Full compensation criteria: an enquiry into relative merits. Eur. J. Law Econ. 18, 223–237.
Tietenberg, T.H., 1989. Indivisible toxic torts: the economics of joint and several liability. Land Econ. 65 (4), 305–319.
Van Huyck, J.B., Battalio, R.C., Beil, R.O., 1990. Tacit coordination games, strategic uncertainty, and coordination failure. Am. Econ. Rev. 80 (1), 234–248.
Wright, R.W., 1985a. Actual causation vs. probabilistic linkage: the bane of economic analysis. J. Legal Stud. 14 (2), 435–456.
Wright, R.W., 1985b. Causation in tort law. California Law Rev. 73, 1735.
Wright, R.W., et al., 2016. Causation, liability and apportionment: comparative interdisciplinary perspectives. Chicago-Kent Law Rev. 91, 445–445.
Young, R., Faure, M., Fenn, P., 2007. Multiple tortfeasors: an economic analysis. Rev. Law Econ. 3 (1), 111–132.