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Group causation theories and deterrence of tortious acts

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Abstract

This paper examines a model with multiple actors, each of whom faces a binary action choice. The action choice imposes harm on a victim that depends on the number of actors who enter or, alternatively, who deviate from a due care standard. The paper examines incentive and welfare effects from per-capita liability under simultaneous as well as sequential action choice. The challenge is to cope with due care standards that, for whatever reasons, need not be efficient. As it turns out, welfare is enhanced in any equilibrium as compared to the situation where none of the actors enter or, alternatively, where all of them meet the due care standard. The range of parameter values, however, where a welfare maximizing outcome in equilibrium is induced by per-capita liability turns out to be rather limited. As an alternative rule, efficient per-capita liability is proposed that would lead to an efficient outcome quite generally for simultaneous as well as sequential action choice.

Keywords Group causation · Per-capita liability · Efficient deterrence · Inefficient due care standards · Sequential action choice

Mathematics Subject Classification K13

1 Introduction

1.1 Scope and findings

To hold an actor liable, there should be a causal link between his tortious act and the victim's harm. In some cases, the but-for test establishes such a link. With multiple tortfeasors, however, this test turns out being too restrictive. To ensure

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compensation of the victim and to deter tortious acts nonetheless, courts take resort to group causation theories such as concerted action, concurrent causes, substantial factors, alternative liability, overdetermined harm and multiple sufficient causes. In many such cases, the resulting damages rule is per-capita liability where negligent actors expect to share liability for the victim's harm in equal parts.

Under joint and several liability, the victim can request the full harm from any one of the tortfeasors. It then becomes the responsibility of the tortfeasors to sort out their respective proportions of liability and payment. For such cases, the German Civil Code, Section 426, explicitly states that joint and several debtors are obliged in equal proportion in relation to one another. Thus, in Germany, per-capita liability follows directly from the law.

In a private conversation, Shahar Dillbary has told me that, under concerted action and alternative liability, there is no real way to apportion and, for that reason, per-capita is the way out. Moreover, when liability is joint and several, the defendant could recover from any one of multiple tortfeasors and, in contrast to German law, the paying party had no right to go after the others. Nonetheless, if the defendant picks a tortfeasor randomly, in expected terms, each defendant would perceive per-capita liability in this case as well. From the incentive perspective, expected damages only matter.

In any case, Dillbary (2016) questions the justification of group causation theories and per-capita liability in terms of deterrence. In fact, dilution of liability may encourage group wrongdoing. Rather than deterrence, Dillbary offers a justification in terms of welfare. He views per-capita liability as a sorting device. Actors are deterred from engaging in welfare decreasing accidents but they are encouraged to engage in welfare increasing ones.

To support his claim, Dillbary offers the following two numerical examples. The first one refers to the benefits from driving tortuously. A number N of actors consider whether to engage in a drag race. Each expects a benefit $b = 40$ from participation. Independent of the number of tortfeasors, the harm to the victim is assumed to be $H = 90$. Since negligent actors share liability equally, each of n tortfeasors is liable for $90/n$ and, hence, the net benefit of each tortfeasor amounts to $\pi_n = 40 - 90/n$. There is dilution of liability because individual liability decreases with the number n of tortfeasors in the range $n > 0$. Moreover, since $\pi_1 = -50 < \pi_2 = -5 < 0 < \pi_3 = 10$, it follows that, for $N \leq 2$, no actor would participate.

For $N > 2$, however, it is a Nash equilibrium when not a single actor is deterred from participation in the drag race. From a welfare perspective, this is not worrisome as, in fact, welfare is at its maximum when all N actors participate. Note, however, it would also be a Nash equilibrium when all actors are deterred. In fact, for a given actor, if no other actor participates, it is a best response for him not to participate either because, otherwise, his payoff would be negative, $\pi_1 < 0$. Therefore, in this example, while the efficient outcome is always a Nash equilibrium, a second equilibrium coexists that features over-deterrence.

The second example has three tortfeasors who lean on a car causing the car to fall over the edge of a cliff. The car is destroyed, its value being $H = 90$. It is assumed

that any tortfeasor alone would not have exerted enough force to push the car over the edge but any two tortfeasors would have.

Based on the but-for test, there would be no causal link between any single actor's wrongdoing and the victim's harm as the same level of harm would have occurred even if, *ceteris paribus*, this actor had not been leaning on the car. In the car example, the but-for causation requirement would prevent compensation of the victim entirely.¹

As a substitute, the suitable group causation theory would offer the required causal link. It seems to be consensus that leaning on the car is a tortious act and that each of the three tortfeasors is liable for $H/3 = 30$. Nevertheless, actors may be tempted to lean negligently on the car as it comes with a private benefit $b = 40$ for each tortfeasor.

When all three are leaning on the car, each tortfeasor ends up with payoff $\pi_3 = b - H/3 = 10$. This constitutes a Nash equilibrium as no single actor could gain from not leaning on the car. In fact, not leaning on the car would deprive her of the benefit b and, while she would escape liability, her net payoff would be zero. Hence, all three leaning on the car is a Nash equilibrium and so per-capita liability would deter not a single actor from the wrongdoing.

From a welfare perspective, though, the lack of deterrence would be less worrisome. Welfare in this Nash equilibrium amounts to $w_3 = 3b - H = 30$. When none of them had leaned on the car, harm would have been avoided but there also would be no private benefits and, hence, welfare would be $w_0 = 0$. Therefore, while the damages rule does not deter tortious acts, it increases welfare.

Note, however, the outcome in this Nash equilibrium falls short of maximizing welfare, i.e., it would not be efficient. Welfare would rather be at its maximum, $w_1 = b = 40$, when a single tortfeasor were leaning on the car. This actor would benefit without causing any harm to the victim. Since $w_1 > w_3$, the Nash equilibrium with all three leaning on the car is inefficient as it comes with under-deterrence.

Note further that the Nash equilibrium in this example too is not unique. The efficient outcome itself coexists as a second Nash equilibrium. The single actor leaning on the car ends up with net payoff $b = 40$ whereas the other two obtain zero. But none of them could unilaterally improve her position because, by a unilateral switch, the payoff would amount to $b - H/2 = -5$ and would be even less. Therefore a single actor leaning on the car is not only efficient. It even constitutes a second Nash equilibrium.

To sum up, in both examples, the efficient outcome is a Nash equilibrium but inefficient equilibria coexist, in one case, with over-deterrence and, in the other case, with under-deterrence. These examples stimulated my curiosity and so I wanted to find out how robust the message drawn from them can be.

To find out, the present paper offers a setting which goes beyond numerical examples but remains sufficiently simple to allow dealing with the issues explicitly. There is a finite set of actors and a victim who is affected by the actors' action choice but remains passive otherwise. Action choice is binary, zero/one. We have

¹ To confirm the view that the but-for standard for overdetermined harm is inadequate, see *Rethinking Actual Causation in Tort Law* *Harvard Law Review*, June 2017.

two interpretations in mind. First, the decision is whether to participate or not so that zero/one means staying out or entering. Second, zero means being in while meeting the due care standard or being in while deviating from it.

For the second interpretation, there is a vast literature on negligence rules that provide efficient precaution incentives. The corresponding contributions have in common that due care standards are specified at efficient due care levels. Per-capita liability as laid out above, however, departs from due care levels that need not be efficient. Nonetheless, in the numerical examples at least, there exists an efficient Nash equilibrium.

The compensation principle as established and extended by the present author shows that Nash equilibria under per-capita liability, where deviations from due care standards occur, come with a welfare level not lower as compared with the situation where all had met these inefficient standards. The principle remains silent, though, on the amount, by which welfare is enhanced in equilibrium. The above numerical examples suggest that welfare may be enhanced up to maximal welfare so that the equilibrium outcome would be efficient. Unfortunately, the efficiency claim has limits even in the proposed setting of binary action choice.

To allow for determining equilibria and doing welfare comparisons explicitly, it is further assumed that benefits from negligent behavior as well as harm to the victim depend on the number of entrants/tortfeasors only but not their identity.

All results apply equally well to the first interpretation where the binary decision is in/out. For notational simplicity, we refer in the text mainly to the first interpretation. In any case, the damages rule is per-capita liability among entrants or among negligent actors. In spite of its simplicity, the setting exhibits a sufficiently rich analytic structure to uncover the limits of the efficiency claim.

Within this setting, the main findings are as follows. First, quite generally, the number of entrants in Nash equilibrium with simultaneous action choice is not unique. The lowest and highest numbers of entrants are derived explicitly.

Second, under sequential action choice, the number of entrants in subgame perfect equilibrium as obtained by backward induction is (generically) unique. More surprisingly, the number of entrants in the subgame perfect outcome is equal to the highest number of entrants in Nash equilibrium.² While backward induction leads to a unique outcome, it need not be the efficient one though (if an efficient Nash equilibrium exists at all).

Third, except for borderline cases, entry occurs in equilibrium and welfare is strictly enhanced but need not be maximized.

Fourth, only if welfare attains its maximum when all actors enter, then the efficient outcome is equal to the Nash equilibrium with the highest number of entrants for sure.

While the above findings are of positive nature as per-capita liability, a rule used in legal practice, is examined, the fifth contribution of the paper is of normative nature. A modified version of per-capita liability is proposed that would provide

² Thus, intuition gained from Cournot versus Stackelberg is thoroughly misleading. The Stackelberg equilibrium under sequential quantity choice, while also being calculated by backward induction, would never be a Cournot (Nash) equilibrium under simultaneous quantity choice.

efficient incentives quite generally. The rule, referred to as efficient per-capita liability, denies liability of entrants (or of negligent actors) as long as harm falls short of a suitably chosen limit. This limit is equal to the harm from the efficient number of entrants. Beyond this limit, some suitably chosen deviators will have to share harm beyond efficient harm in equal parts.

Efficient per-capita liability may be at conflict with discrimination issues, at least when actors move simultaneously. When they move sequentially, however, it may be justifiable to discriminate among them according to the stage when it is their turn to decide. In any case, efficient per-capita liability would provide efficient incentives. Inefficient outcomes would not occur, no matter whether action choice is simultaneous or sequential.

1.2 Relevant literature

There is a vast literature on damages rules for cases of multiple tortfeasors. A prominent source of a formal analysis would be Kornhauser and Revesz (1989). But there also exist prominent textbook treatments of tort law such as William and Posner (1987) and Shavell (1987, 2004). This literature mainly deals with rules that provide efficient incentives. For negligence rules, this means that due care standards are specified at their efficient level.

Miceli and Segerson (1991) examine a setting with two actors who, at the first stage, simultaneously take an entry decision. At the second stage, the actors who have entered simultaneously decide on their activity levels. These authors do backward induction as the present paper does. By insisting on a socially best response in every subgame, however, they find out that the subgame perfect outcome fails to maximize welfare, at least for the damages rule proposed by them. The present paper, in contrast, deals with the subgame perfect outcome, not insisting on efficient replies off the equilibrium path.

The main references of the present paper, however, are Dillbary (2013, 2016) where due care standards may be inefficient and where per-capita liability leads to second best problems that, as such, are notoriously more demanding to handle. The compensation principle as developed over time by the present author, however, provides guidance.

A first version of the compensation principle was introduced in Schweizer (2005a) for a situation with two actors and in Schweizer (2005b) for multiple actors. These early versions were still confined to efficient reference profiles. The most general version so far can be found in Schweizer (2024). It allows for multiple actors as well as for inefficient reference profiles and covers the simultaneous move game of the present setting. The extension to sequential choice with multiple actor is provided by the present paper.

1.3 Organizational structure

The present paper is organized as follows. In Sect. 2, the basic model of binary action choice under per-capita liability is introduced. In Sect. 3, the Nash equilibria for simultaneous action choice are identified as functions of the parameter configuration. In Sect. 4, backward induction for sequential action choice is carried out. Section 5 summarizes the welfare statements and provides numerical examples. In Sect. 6, efficient per-capita liability is specified as a rule that would provide efficient incentives quite generally. Section 7 concludes. In the appendix, the extension of the compensation principle is established.

2 The model

Each actor i out of a finite set $I = \{1, \dots, N\}$ chooses an action x_i from the set $\{0, 1\}$ of available alternatives. If actor i decides $x_i = 0$ we say that i stays out. If he decides $x_i = 1$ we say that i enters. An alternative interpretation would be that all actors are in. In this case, $i = 0$ means that i meets the due care standard while $x_i = 1$ means that he deviates. The results hold for both interpretations. For simplicity, the text mainly refers to the first one.

An action profile $x = (x_1, \dots, x_N)$ lists exactly one action of each actor. At action profile x , the number of entrants is $t(x) = \sum_{i \in I} x_i$. By assumption, harm $H_0 = 0 \leq H_n$ to the victim as well as the private benefit $b_n > 0$ before damages of each entrant depend on the number $0 < n \leq N$ of entrants but not their identity i .

The drag race example from the introduction has $H_0 = 0 < H_n = H = 90$ for $0 < n \leq N$ and the car example has $N = 3$ and $H_0 = H_1 = 0 < H_2 = H_3 = H = 90$. Both examples have $b_0 = 0 < b_n = 40$ for all $0 < n \leq N$.

Under per-capita liability, actors who stay out (or meet the standard) are not liable whereas entrants (or negligent actors) are liable for total harm in equal shares. The victim's claim is harm H_n when $n > 0$ actors have entered, in which case each entrant owes damages $h_n = H_n/n$ to the victim.

With n entrants, welfare amounts to $w(0) = 0$ and, for all $0 < n \leq N$,

$$w(n) = n \cdot b_n - H_n = n \cdot (b_n - h_n) = n \cdot \pi_n \quad (1)$$

where $\pi_n = b_n - h_n$ denotes the benefit net of damages of each entrant.

Under per-capita liability, the payoff of actor i net of damages amounts to

$$\phi_i(x) = \pi_{t(x)} \cdot x_i \quad (2)$$

as a function of the chosen action profile x . The payoff functions (2) define a game. Rational actors end up, when they choose their actions simultaneously, with a Nash equilibrium of this game or, when actions are chosen sequentially, with a subgame perfect outcome. An action profile is a Nash equilibrium when it consists of mutually best responses. A subgame perfect equilibrium is obtained by backward induction. Formal details are provided in the next sections.

The victim is not an active player but, as she is fully compensated, her payoff including damages amounts to $\phi_v(x) = 0$, no matter, what actions x are chosen.

Relative to a given reference profile x^o , a damages rule is called compensatory when no actor who keeps to the reference profile suffers from deviations by others, i.e., $\phi_i(x_i^o, x_{-i}) \geq \phi_i(x^o)$ holds for all i and all deviations x_{-i} by the other actors and if the victim is compensated for any deviations, i.e., $\phi_v(x) \geq \phi_v(x^o)$ holds for all action profiles. In this sense, per-capita liability is compensatory relative to the reference profile $x^o = (0, \dots, 0)$. By (1), this reference profile is efficient (i.e., welfare maximizing) if and only if $\max[\pi_1, \dots, \pi_N] \leq 0$. In this case, it follows from the compensation principle (see the appendix) that any Nash equilibrium under simultaneous action choice as well as any subgame perfect outcome under sequential action choice must be efficient.

In all other cases, i.e., if $\max[\pi_1, \dots, \pi_N] > 0$, it follows from the compensation principle that any Nash equilibrium and any subgame perfect outcome comes with a higher welfare level than under the reference profile, in our case $w(0) = 0$. The compensation principle does not tell us by what amount welfare is increased though. For the setting of binary action choice, this issue will be fully settled in the next two sections.

3 Simultaneous action choice

A Nash equilibrium in pure strategies consists of an action profile $\hat{x} = (\hat{x}_1, \dots, \hat{x}_N)$ so that no actor can improve his payoff by unilaterally deviating from it, i.e.,

$$\phi_i(\hat{x}_i, \hat{x}_{-i}) \geq \phi_i(x_i, \hat{x}_{-i})$$

holds for all actors i and for all deviations $x_i \neq \hat{x}_i$ by actor i . Let $\hat{x} = 1^{\hat{n}} = (1, \dots, 1, 0, \dots, 0)$ denote the action profile where actors $i \leq \hat{n}$ enter but the remaining ones do not. Since net benefits of an entrant depend only on the total number of entrants, the following must be true: if $\hat{x} = 1^{\hat{n}}$ is a Nash equilibrium then any action profile $x = (x_1, \dots, x_N)$ with the same number $t(x) = \hat{n}$ of entrants is also a Nash equilibrium. This allows us to say the number \hat{n} of entrants is Nash when $1^{\hat{n}}$ is a Nash equilibrium.

Finite games do not necessarily have a Nash equilibrium in pure strategies. In our model, however, there always exist such equilibria. The next two propositions show how the lowest number \hat{n}_L and the highest number \hat{n}_H that are Nash can be found in a constructive way.

Proposition 1 The lowest number \hat{n}_L that is Nash is determined as follows:

- (i) If $\pi_1 \leq 0$ then $\hat{n}_L = 0$.
- (ii) If $\pi_{\hat{n}+1} \leq 0 < \min[\pi_1, \dots, \pi_{\hat{n}}]$ then $\hat{n}_L = \hat{n}$.
- (iii) If $0 < \min[\pi_1, \dots, \pi_N]$ then $\hat{n}_L = N$.

Proof To prove claim (ii), suppose $\pi_{\hat{n}+1} \leq 0 < \min[\pi_1, \dots, \pi_{\hat{n}}]$ and, in particular, $\pi_0 = 0 < \pi_1$. Then $n = 0$ cannot be Nash. In fact, given profile $(0, \dots, 0)$ where each actor receives zero payoff, any one of them, say, $i = 1$ could deviate ending up with a positive payoff $\pi_1 > 0$. Therefore $(0, \dots, 0)$ cannot be a Nash equilibrium. If $0 < n < \hat{n}$ then $\pi_{n+1} > 0$. Such a number n can neither be Nash. In fact, consider the action profile $1^n = (1, \dots, 1, 0, \dots, 0)$ where actors $i \leq n$ deviate but actors $j > n$ do not. Since $n + 1 \leq \hat{n}$, it follows that $\pi_{n+1} > 0$ and, hence, actor, say $j = n + 1$, could deviate, ending up with a positive payoff π_{n+1} compared with payoff zero under 1^n . Therefore no $0 \leq n < \hat{n}$ can be Nash.

The profile $1^{\hat{n}}$, however, is Nash. In fact, any actor $i \leq \hat{n}$ makes positive payoff $\pi_{\hat{n}} > 0$ and would loose from deviating with $x_i = 0$. Actor $j > \hat{n}$ makes zero payoff. Yet, by deviating with $x_j = 1$, his payoff $\pi_{\hat{n}+1} \leq 0$ would not be higher and, hence, $1^{\hat{n}}$ is a Nash equilibrium. Since $n < \hat{n}$ is not Nash, it follows that $\hat{n} = \hat{n}_L$ is the lowest number of entrants (deviators) that is Nash. Claim (ii) is established. Claims (i) and (iii) can be established similarly. \square

This proposition allows for the following welfare comparisons. Under configuration (i), $\hat{n}_L = 0 \leq n^*$ is obviously true and, hence, this Nash equilibrium need not maximize welfare. Under configuration (ii), welfare is enhanced as $w(\hat{n}_L) = \hat{n}_L \cdot \pi_{\hat{n}_L} > 0$ holds for sure but it need not maximize welfare. Moreover, cases with over-deterrence, $\hat{n}_L < n^*$ as well as with under-deterrence, $n^* < \hat{n}_L$, can occur. Under configuration (iii), finally, $n^* \leq \hat{n}_L = N$ is obviously true. In this case, welfare is enhanced, $w(\hat{n}_L) = \hat{n}_L \cdot \pi_{\hat{n}_L} > 0$, but \hat{n}_L need not maximize welfare. Numerical examples supporting these claims are presented in section 5 below.

For the next result, to avoid case distinctions of little interest, we assume that parameter configurations are generic in the sense that $\pi_n \neq 0$ holds for all $0 < n \leq N$.³

Proposition 2 (generic parameter configurations) The highest number \hat{n}_H that is Nash is determined as follows:

- (i) If $0 < \pi_N$ then $\hat{n}_H = N$.
- (ii) If $\max[\pi_{n+1}, \dots, \pi_N] < 0 < \pi_n$ then $\hat{n}_H = n$.
- (iii) If $\max[\pi_1, \dots, \pi_N] < 0$ then $\hat{n}_H = 0$.

To economize on space, the proof is omitted. The argument is similar to the one in the Proof of Proposition 1.

As a first corollary of the above proposition, it is easily seen that, in Nash equilibria with the highest number of deviators, there is under-deterrence as, in fact, $n^* \leq \hat{n}_H$ holds in all cases (i)–(iii). Under-deterrence may be strict.

Moreover, the proposition allows for the following welfare comparison. In case (i), while welfare is enhanced, $w(\hat{n}_H) = N \cdot \pi_N > w(0)$, it need not maximize welfare, i.e., $n^* < \hat{n}_H$ cannot be ruled out. The same holds true for case (ii). In case (iii),

³ The assumption holds generically in the following sense: when parameter values are drawn from a distribution that has a density function, then the assumption is met with probability one.

however, entry is fully deterred and this is efficient in configuration (iii). All the above claims are supported by numerical examples in Sect. 5 below.

For sake of completeness, the next result identifies the parameter configurations where the number of entrants in Nash equilibrium would be unique.

Proposition 3 (Generic parameter configurations)

- (i) $\hat{n} = 0$ is the unique number that is Nash if and only if $\max[\pi_1, \dots, \pi_N] < 0$.
- (ii) $0 < \hat{n} < N$ is the unique number that is Nash if and only if

$$\max[\pi_{\hat{n}+1}, \dots, \pi_N] < 0 < \min[\pi_1, \dots, \pi_{\hat{n}}].$$

- (iii) $\hat{n} = N$ is the unique number that is Nash if and only if

$$0 < \max[\pi_1, \dots, \pi_N].$$

It follows from the above proposition that the number of tortfeasors in Nash equilibrium is unique only when the net benefits from entry changes its sign at most once as the number of entrants increases and, if it does, the change is downwards.

The above propositions concern the outcome under rational play when the actors move simultaneously. The next section deals with sequential choice.

4 Sequential action choice

In this section, we consider the stage game with sequential action choice. Actors move in line with their index, actor $i = 1$ at stage 1 of the game, actor $i = 2$ at stage 2 and so on. A strategy consists now of a complete contingent plan for each actor. The subgame perfect equilibrium is calculated by backward induction. Suppose, at the final stage N , actor N sees that n actors have previously entered. Then he enters, $x_N^{sp}(n) = 1$, when $\pi_{n+1} > 0$ and $x_N^{sp}(n) = 0$ otherwise.

Suppose, at stage i , actor i sees that n actors have previously entered. Moreover, he anticipates correctly that n_s more actors will enter at subsequent stages when i enters at stage i . Then i enters if $\pi_{n+1+n_s} > 0$ but not otherwise. Backward induction is continued all the way down to agent $i = 1$. For him, there exist no actors that decide earlier. By backward induction, however, he correctly anticipates the number n_1 of entrants after him when he enters. Therefore he enters when $\pi_{n_1+1} > 0$ but not otherwise. Starting from his decision at stage 1, the equilibrium path evolves stage by stage. The resulting equilibrium path is referred to as subgame perfect outcome.

For generic parameter values satisfying $\pi_n \neq 0$ for all $0 < n \leq N$, the subgame perfect equilibrium is unique because, at no stage, an actor would be indifferent between entering and staying out and, hence, the subgame perfect outcome is unique as well. This is in contrast to simultaneous action choice where multiple Nash equilibria cannot be ruled out. The proposed setting allows to determine the subgame perfect outcome explicitly as the next proposition shows.

Proposition 4 (generic parameter configurations) Under sequential action choice, the subgame perfect outcome is of shape $x^{sp} = (1, \dots, 1, 0, \dots, 0)$ where the first n^{sp} actors enter while the last $N - n^{sp}$ ones do not. This number of entrants is equal to the maximum number that would be Nash under simultaneous action choice, i.e., $n^{sp} = \hat{n}_H$.

Proof The proof follows easily from proposition 2. We deal with case (ii) where $\hat{n} = \hat{n}_H$ satisfies $\max[\pi_{\hat{n}+1}, \dots, \pi_N] < 0 \leq \pi_{\hat{n}}$. We claim that, along path $x = (1, \dots, 1, 0, \dots, 0)$ with \hat{n} entrants, no actor has an incentive to deviate. To prove this claim, take any actor $i \leq \hat{n}$. If he keeps to the path, his payoff is $\pi_{\hat{n}} \geq 0$ and, in fact, $\pi_{\hat{n}} > 0$ due to the assumption of generic parameter values. If he would deviate, his payoff would be zero and, hence, such an actor has no incentive to deviate. Take an actor $j > \hat{n}$. If she keeps to the path, her payoff is zero. If she would deviate, this may trigger entry at later stages. In any case, the total number of entrants would be $n > \hat{n}$ at the end of the game and, hence, her payoff would be $\pi_n < 0$. Therefore she has no incentive to enter and the proposition is fully established when \hat{n}_H is determined according to Proposition 2 (ii).

The cases (i) and (iii) of Proposition 2 can be handled similarly. \square

After having provided a full account of rational outcomes under both simultaneous as well as sequential action choice when per-capita liability is in place, the next section summarizes the welfare conclusions.

5 Welfare in equilibrium

Based on the findings of the previous sections, welfare comparisons can be summarized as follows. Since $\hat{n}_H = n^{sp}$, it is sufficient to compare $w(\hat{n}_L)$ and $w(\hat{n}_H) = w(n^{sp})$ with $w(n^*)$ when the number n^* of entrants is efficient. To avoid uninteresting case distinctions, as in Propositions 2 and 3, only generic parameter configurations with $\pi_n \neq 0$ for $0 < n \leq N$ are taken into account.

- (1) In Nash equilibria with the lowest number of entrants, welfare is strictly enhanced, $w(\hat{n}_L) > w(0)$, except in the case where $\hat{n}_L = 0$. But welfare need not be maximized in such equilibria and there may be over- or under-deterrence.
- (2) In Nash equilibria with the highest number of entrants, there is always (weakly) insufficient deterrence. Except in the case where $\hat{n}_H = 0$, welfare is strictly enhanced, $w(\hat{n}_H) > w(0)$, but welfare need not be maximized.
- (3) When staying out is efficient, $w(n^*) = w(0)$, then $\hat{n}_L = \hat{n}_H = 0$ and, hence, staying out maximizes welfare. When $0 < \pi_N = \max[\pi_1, \dots, \pi_N]$ then the Nash equilibrium with the highest number of entrants maximizes welfare, $w(\hat{n}_H) = w(N) = w(n^*)$. If, on top of it, $\min[\pi_1, \dots, \pi_N] < 0$ then an inefficient Nash equilibrium coexists.

The following three numerical examples have in common that the efficient outcome is not a Nash equilibrium.

Example 1 There are $N = 3$ actors. The net benefit of an entrant is $\pi_1 = 26 > \pi_2 = 2$ and $\pi_2 < \pi_3 = 6$. These benefits are single-dipped with dip at $n = 2$. Moreover, since $w_1 = 26 > w_3 = 18$, the efficient number of entrants is $n^* = 1$ but, as follows from Proposition 3 (iii), $\hat{n}_L = \hat{n}_H = 3$ is the unique number that is Nash. In this example, the efficient outcome is not a Nash equilibrium.

Example 2 There are $N = 4$ actors. The net benefit of an entrant is $\pi_1 = 15 > \pi_2 = 3 > 0 > \pi_3 = -1$ and $\pi_3 < 0 < \pi_4 = 1$. These benefits are single-dipped with dip at $n = 3$. It follows from Propositions 1 (i) and 2 (i) that $\hat{n}_L = 2 < \hat{n}_H = 4$. Moreover, since $w_1 = 15 > w_2 = 6 > w_4 = 4$, it follows that the efficient number of entrants would be $n^* = 1$. In this example, Nash equilibria even with the lowest number of entrants come with strict under-deterrence.

Example 3 There are $N = 3$ actors. The net benefit of an entrant is $\pi_1 = -5 < 0 < \pi_2 = 25$ and $\pi_2 > \pi_3 = 5$. These net benefits are single-peaked with peak at $n = 2$. By Propositions 1 (i) and 2 (i), $\hat{n}_L = 0 < \hat{n}_H = 3$ must hold. Since $w_2 = 50 > w_3 = 15$, the efficient number of entrants would be $n^* = 2$. In this example, there exist Nash equilibria with strict over-deterrence and others with strict under-deterrence. The efficient number of entrants, however, is not Nash. In terms of welfare, the equilibrium with full deterrence comes with zero welfare whereas the equilibrium with insufficient deterrence comes with positive welfare.

6 Efficient per-capita liability

So far, the analysis was of positive nature in the sense that per-capita liability was understood as a rule used in legal practice. It was shown where it leads to when actors behave rationally. In general, the outcome falls short of maximizing welfare. The present section takes a normative perspective by proposing a modified rule that would ensure an efficient outcome quite generally.

Let $n^* > 0$ denote the efficient number of entrants.⁴ We take $x^* = 1^{n^*} = (1, \dots, 1, 0, \dots, 0)$ with n^* entrants as reference profile. For notational simplicity, let me assume that the efficient number n^* of entrants is unique. Under efficient per-capita liability, agents $i = 1, \dots, n^*$ are never held liable. For these agents, $x_i = x_i^* = 1$ is a dominant strategy, which they will use in any equilibrium.

This leaves the set $J = \{j \in I : j > n^*\}$ as the only active players left who have to decide while facing the reference profile $x_J^* = (0, \dots, 0)$. Let $\lambda(x_J) = \sum_{j \in J} x_j$ denote the number of entrants in excess of the n^* who enter for sure. Then efficient per-capita liability is specified as follows.

⁴ If $n^* = 0$ then ordinary per capita liability would implement efficient outcomes only and no modification would be needed in this case.

If $\lambda(x_J) = 0$ then $x_i = x_i^*$ for all $i \in I$. In this case, no actor is liable, i.e., $d_i(x) = 0$ for all $i \in I$ and so the victim ends up with payoff $\phi_v(x^*) = -H_{n^*}$. Actors $i \leq n^*$ obtain $\phi_i(x^*) = b_{n^*}$ whereas actors $j \in J$ obtain $\phi_j(x^*) = 0$.

If, however, $\lambda(x_J) > 0$ then the set $\Lambda(x_J) = \{j \in J : x_j = 1 > x_j^* = 0\}$ of actors who enter is non-empty. Their joint deviation x_J is the but-for cause of harm $\Delta_v(x_J) = \max [H_{n^*+\lambda(x_J)} - H_{n^*}, 0]$ to the victim.⁵ Under efficient per-capita liability, the actors $\Lambda(x_J)$ are held liable for harm based on but-for causation in equal shares.

But their deviation is also the but-for cause of harm

$$\Delta_i(x_J) = \max [b_{n^*} - b_{n^*+\lambda(x_J)}, 0]$$

to actor $i \leq n^*$.⁶

Under efficient per-capita liability, the actors $\Lambda(x_J)$ are held liable for harm $\Delta_i(x_J)$ in equal shares. This rule is compensatory relative to the efficient reference profile x^* for the following reasons.

The victim is compensated or even over-compensated because the compensation requirement

$$\phi_v(x_J) = -H_{n^*+\lambda(x_J)} + \Delta_v(x_J) \geq -H_{n^*} = \phi_v(x_J^*)$$

is satisfied for any deviation x_J from $x_J^* = (0, \dots, 0)$. For similar reasons, the compensation requirement is also satisfied for any actor $i \leq n^*$ because

$$\phi_i(x_J) = b_{n^*+\lambda(x_J)} + \Delta_i(x_J) \geq b_{n^*} = \phi_i(x_J^*)$$

holds for any such actor. Finally, since $\phi_j(x_j^*, x_{-j}) = 0 = \phi_j(x_J^*) = 0$, the compensation requirement is also satisfied for any actor $j \in J$ who, by choosing $x_j = x_j^* = 0$, keeps to the reference profile. The next proposition then follows from the compensation principle as established in the appendix.

Proposition 5 Suppose efficient per-capita liability as specified above is in place and suppose \hat{x} is any Nash equilibrium of the simultaneous move game and x^{sp} is any subgame perfect outcome under sequential action choice. Then all of these outcomes must be efficient. Moreover:

- (i) $\hat{x}_i = x_i^{sp} = x_i^* = 1$ holds for all $i \leq n^*$
- (ii) $\phi_v(\hat{x}) = \phi_v(x_i^{sp}) = \phi_v(x_i^*) = -H_{n^*}$ holds for the victim
- (iii) $\phi_j(\hat{x}) = \phi_j(x_i^{sp}) = \phi_j(x_i^*) = 0$ holds for all actors $j \in J$
- (iv) $\phi_i(\hat{x}) = \phi_i(x_i^{sp}) = \phi_i(x_i^*) = b_{n^*}$ holds for all actors $i \leq n^*$

⁵ If $H_{n^*+\lambda(x_J)} - H_{n^*} < 0$ then the victim would benefit. In line with principles of tort law, such benefits are kept for free.

⁶ Note that, if $b_1 \leq b_2 \leq \dots \leq b_N$, then $\Delta_i(x_J) = 0$ for all x_J .

Claim (i) is obviously true because actors $i \leq n^*$ make use of their dominant strategy. Claims (ii)–(iv) spell out payoff equivalence for the setting of binary action choice as established by the compensation principle.

Under simultaneous action choice, efficient per-capita liability discriminates among actors merely based on their identity. On legal grounds, this may not be acceptable. Under sequential action choice, however, actors differ according to when it is their turn to decide. For this reason, efficient per-capita liability may more likely be acceptable under sequential action choice. In any case, the rule would provide efficient incentives.

7 Concluding remarks

Ordinary per-capita liability may not deter entry (or negligent behavior). But even if it does not, it typically enhances welfare. This part of Dillbary's claim is true quite generally. But even in our simple setting of binary action choice, the equilibrium outcome under per-capita liability need not maximize welfare. Only if welfare attains its maximum when all actors enter or, alternatively, when all behave negligently then the equilibrium outcome will also maximize welfare for sure. Efficient per-capita liability as specified for the binary choice setting, in contrast, would provide efficient incentives quite generally.

The lesson from the extended version of the compensation principle remain valid far beyond the binary choice setting. Any damages rule compensatory relative to an efficient reference profile induces exclusively efficient outcomes. This is true, no matter whether actions are chosen simultaneously or sequentially provided, of course, that all actors behave rationally.

Appendix

In this appendix, a general compensation principle is established that covers both simultaneous as well as sequential action choice. We allow that all affected parties are active players. In particular, victims may also have to choose an action.

In this sense, player $i \in I = \{1, \dots, N\}$ chooses his action x_i from his (strategy) set S_i . This set may contain more than two alternatives. Individual benefits before damages may depend on the identity of an actor. An action profile x belongs to the Cartesian product $S_1 \times \dots \times S_N$. The payoff $\phi_i(x)$ of player i after damages is a function of the action profile and so is welfare $w(x) = \sum_{i \in I} \phi_i(x)$.

For a given reference profile x^o , suppose the compensation requirement

$$\phi_i(x_i^o, x_{-i}) \geq \phi_i(x^o) \quad (3)$$

is satisfied for all $i \in I$, i.e., any player who keeps to the reference profile is compensated or even over-compensated for deviations by others.

To establish the compensation principle, let \hat{x} be a Nash equilibrium of this game when players choose their strategies simultaneously and x^{sp} the subgame perfect outcome when, at stage 1, player 1 chooses x_1 before, at stage 2, player 2 chooses x_2 and so on. Then the following result is valid.

Proposition 6 Suppose the compensation requirements (3) are satisfied for all players $i \in I$ who keep to the reference profile. Then, for any Nash equilibrium \hat{x} with simultaneous moves and any subgame perfect outcome x^{sp} with sequential moves, the following claims are valid:

- (i) $\phi_i(\hat{x}) \geq \phi_i(x^o)$ holds for all players i and, hence, $w(\hat{x}) \geq w(x^o)$
- (ii) when the reference profile x^o maximizes welfare then even $\phi_i(\hat{x}) = \phi_i(x^o)$ holds for all players (payoff equivalence) and, hence, $w(\hat{x}) = w(x^o)$
- (iii) $\phi_i(x^{sp}) \geq \phi_i(x^o)$ holds for all players i and, hence, $w(x^{sp}) \geq w(x^o)$
- (iv) when the reference profile x^o maximizes welfare then even $\phi_i(x^{sp}) = \phi_i(x^o)$ holds for all players (payoff equivalence) and, hence, $w(x^{sp}) = w(x^o)$

Proof Claim (i): In Nash equilibrium, no player can gain from a unilateral deviation and, hence, $\phi_i(\hat{x}) \geq \phi_i(x_i^o, x_{-i}^N)$ holds for all $i \in I$. Since the compensation requirements (3) are satisfied, $\phi_i(x_i^o, \hat{x}_{-i}) \geq \phi_i(x^o)$ and, hence, $\phi_i(\hat{x}) \geq \phi_i(x^o)$ holds for all players $i \in I$. By adding up these inequalities, it follows that $w(\hat{x}) \geq w(x^o)$ must hold. Claim (i) is established.

Claim (ii): when the reference profile maximizes welfare, then welfare under \hat{x} cannot strictly be higher, i.e., $w(\hat{x}) = w(x^o)$ and, hence, $\phi_i(\hat{x}) = \phi_i(x^o)$ must hold with equality for all players $i \in I$. Claim (ii) is established.

Claim (iii): Proving claim (iii) needs more notation. At stage i , player i observes the actions x_1, \dots, x_{i-1} that have been chosen at previous stages. Moreover, by backward induction, player i anticipates the list $a_i[x_1, \dots, x_{i-1}, x_i]$ of actions that will be taken at subsequent stages as a function of both the previously chosen actions and his own action x_i . In subgame perfect equilibrium, player i will choose an action $x_i^{sp} \{x_1, \dots, x_{i-1}\}$ that maximizes his payoff. This action satisfies

$$\begin{aligned} & \phi_i(x_1, \dots, x_{i-1}, x_i^{sp} \{x_1, \dots, x_{i-1}\}, a_i[x_1, \dots, x_{i-1}, x_i^{sp} \{x_1, \dots, x_{i-1}\}]) \\ & \geq \phi_i(x_1, \dots, x_{i-1}, x_i, a_i[x_1, \dots, x_{i-1}, x_i]) \end{aligned}$$

for all x_1, \dots, x_i and, in particular, for $x_i = x_i^o$. It follows from the compensation requirement (3) with respect to player i that

$$\phi_i(x_1, \dots, x_{i-1}, x_i^{sp} \{x_1, \dots, x_{i-1}\}, a_i[x_1, \dots, x_{i-1}, x_i^{sp} \{x_1, \dots, x_{i-1}\}]) \geq \phi_i(x^o)$$

holds, no matter what actions x_1, \dots, x_{i-1} have previously been chosen.

At stage 1, player $i = 1$ chooses an action x_1^{sp} that maximizes his payoff while anticipating the actions $a_1[x_1]$ to be taken at all later stages of the game. This action satisfies $\phi_1(x_1^{sp}, a_1[x_1^{sp}]) \geq \phi_1(x_1, a_1[x_1])$ for all actions x_1 and, in particular, for $x_1 = x_1^o$ and, hence,

$$\phi_1(x_1^{sp}, a_1[x_1^{sp}]) \geq \phi_1(x_1^o, a_1[x_1^o]) \geq \phi_1(x^o)$$

holds as follows from the compensation requirement (3) with respect to player $i = 1$.

Given this subgame perfect equilibrium, the subgame perfect outcome $x^{sp} = (x_1^{sp}, a_1[x_1^{sp}])$ will evolve. It follows that, in this subgame perfect outcome, $\phi_i(x^{sp}) \geq \phi_i(x^o)$ holds for all actors $i \in I$.

By adding up these inequalities, it follows that

$$w(x^{sp}) = \sum_{i \in I} \phi_i(x^{sp}) \geq \sum_i \phi_i(x^o) = w(x^o)$$

holds for any subgame perfect outcome x^{sp} and so claim (iii) is established. Claim (iv) then follows from claim (iii) as claim (ii) follows from claim (i). The general version of the compensation principle is fully established.

It remains to construct the functions $a_i[x_1, \dots, x_{i-1}, x_i]$ explicitly by backward induction. At the final stage N , there are no subsequent stages left and, hence, $a_N[x_1, \dots, x_N]$ consists of the empty list whereas $a_{N-1}[x_1, \dots, x_{N-1}] = x_N^{sp}(x_1, \dots, x_{N-1})$.

Suppose $a_i[x_1, \dots, x_i]$ has already been constructed down to stage i . Take $x_i^{sp}\{x_1, \dots, x_{i-1}\}$ as defined above. Then we specify

$$a_{i-1}[x_1, \dots, x_{i-1}] = (x_1, \dots, x_{i-1}, x_i^{sp}\{x_1, \dots, x_{i-1}\}, a_i[x_1, \dots, x_i^{sp}\{x_1, \dots, x_{i-1}\}])$$

at stage i . By repeating this process backwards, the functions $a_i[x_1, \dots, x_i]$ are constructed for $i = N, N-1, \dots, 1$ and we are done. \square

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