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I. INTRODUCTION

Causation is one of the most intricate and complex issues in the law. As Richard Wright stated, "in all of tort law, there is no concept which has been as pervasive and yet elusive as the causation requirement."[1] Among the issues raised by causation requirements, overdetermination is, at least conceptually, particularly difficult to deal with. The reason is that applying standard criteria of causation—based on necessity requirements (e.g., but-for-test, *sine qua non* conditions)—to overdetermined-causation cases fails to give coherent and comprehensive answers to courts. The most famous example is the following: two fires, lighted separately by tortfeasors X and Y, merge together. The merged fire then destroys the plaintiff's house. "Here, application of the 'but-for' test would exonerate both X and Y if each fire were large enough to burn the house by itself. X's fire was not causal. Even in the absence of X's fire, the house would have been burned by Y's fire."[2] So, X's fire is not a but-for cause nor is Y's fire. And the same thing could be said about Y's fire. Y's fire is not causal. The applica-

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1. Richard Wright, *Causation in Tort Law*, 73 CALIF. L. REV. 1735, 1737 (1985). Prosser states: "There is perhaps nothing in the entire field of law which has called forth more disagreement, or upon which the opinions are in such a welter of confusion. Nor, despite the manifold attempts which have been made to clarify the subject, is there yet any general agreement as to the proper approach." William M. Landes & Richard A. Posner, *Causation in Tort Law: An Economic Approach*, 12 J. LEGAL STUD. 109, 109 (1983); *see also, e.g.*, RICHARD GOLDBERG, PERSPECTIVES ON CAUSATION vii (2011); HERBERT L.A. HART & TONY A. M. HONORÉ, CAUSATION IN THE LAW xxxiii (2d ed. 1985); JOHN L. MACKIE, THE CEMENT OF THE UNIVERSE: A STUDY ON CAUSATION 1 (L. Jonathan Cohen ed., 1974); MICHAEL MOORE, CAUSATION AND RESPONSIBILITY: AN ESSAY IN LAW, MORALS, AND METAPHYSICS 3 (2009); Tony A. M. Honoré, *Necessary and Sufficient Conditions in Tort Law*, *in* PHILOSOPHICAL FOUNDATIONS OF TORT LAW 363–85 (D. G. Owen ed., 1995); Jane Stapleton, *Legal Cause: Cause-in-Fact and the Scope of Liability for Consequences*, 54 VAND. L. REV. 941, 968 (2001) (upholding the "dignity of the law" requires modifying the but-for standard); Richard Wright, *Once More into the Bramble Bush: Duty, Causal Contribution, and the Extent of Legal Responsibility*, 54 VAND. L. REV. 1071, 1072 (2001).

2. David A. Fischer, *Insufficient Causes*, 94 KY. L. J. 277, 280 (2005).

tion of the but-for test in these circumstances leads to dilemmas and paradoxes; holding that none of the two wrongdoers be liable violates common sense and the principles of distributive and corrective justice.[3]

This failure explains why legal thought and jurisprudence has tried to elaborate further on causation requirements. For example, in the United States, chapter five of the *Third Restatement of Torts* is dedicated to this issue.[4] The *Third Restatement* advocates new methods to deal with overdetermined causation cases and uses interesting concepts, such as multiple sufficient causes, multiple sufficient causal sets, preemption, and trivial contribution.[5] In Europe, the *Principles of European Tort Law* (PETL) deals with this issue.[6] From a larger perspective, legal scholars in the United States and elsewhere have also written extensively on this topic to reach better and more convincing solutions. For example, following Herbert L.A. Hart, Tony A.M. Honoré, and John Mackie, Richard Wright has elaborated the NESS criterion to solve some of these paradoxes.[7] Others, like Jane Stapleton, think that the law has to go further and "should adopt a notion of a 'cause' that is wider than the relation of necessity that is encapsulated in the but-for test."[8] These scholars recognize the relevance of causal contribution, *i.e.* a factor may have had a causal role due to a positive, even unnecessary, contribution "to the relevant mechanism by which the phenomenon came about."[9] Other scholars doubt that the human mind

3. *See* Jules L. Coleman, *Tort Law and the Demands of Corrective Justice*, 67 IND. L. J. 349 (1992).

4. *See* RESTATEMENT (THIRD) OF TORTS: LIABILITY FOR PHYSICAL AND EMOTIONAL HARM § 27 (AM. LAW INST. 2010); *see also id.* § 36.

5. Courts and scholars have long recognized the problem of overdetermined harm—harm produced by multiple sufficient causes—and the inadequacy of the but-for standard for these situations. *See* Charles E. Carpenter, *Concurrent Causation*, 83 U. PA L. REV. 941, 947 (1935); Robert J. Peaslee, *Multiple Causation and Damage*, 47 HARV. L. REV. 1127, 1127 (1934).

6. *See* PRINCIPLES OF EUROPEAN TORT LAW art. 3:102 (2005) ("In case of multiple activities, where each of them alone would have caused the damage at the same time, each activity is regarded as a cause of the victim's damage."); *id.* art. 3:105 ("In the case of multiple activities, when it is certain that none of them has caused the entire damage or any determinable part thereof, those that are likely to have [minimally] contributed to the damage are presumed to have caused equal shares thereof.").

7. The NESS test considers that a factual cause is a "Necessary Element of a Sufficient Set." *See* Wright, *supra* note 1, at 1788; Chris Miller, *NESS for Beginners*, *in* PERSPECTIVES ON CAUSATION 323 (Richard Goldberg ed., 2011).

8. Jane Stapleton, *Unnecessary Causes*, 129 LAW Q. REV. 39, 39 (2013).

9. *Id.* ("This article argues that a preferable approach for private law is a clear recognition of a general principle that all that is required before the relation between a factor and the existence of a phenomenon will be recognised as 'causal' is that: either, but for the factor, the phenomenon would have been prevented; or the factor resulted in some positive contribution to the relevant mechanism by which the phenomenon came about. In other words, that, when determining what it means to be a 'cause,' private law should adopt a notion of a 'cause' that is wider than the relation of necessity that is encapsulated in the but-for test."); *see* PRINCIPLES OF EUROPEAN TORT LAW art. 3:105 (2005). Article 3:105 uses the term of "partial causation" and adds "those that are likely to have [minimally] contribut-

could ever capture all the difficulties encapsulated in causation requirements.[10] The aim of this article is to add to this literature on overdetermined causation cases and show that economic models could be very useful to legal scholars.

The causation issue has a long and complicated story in law and economics. Indeed, the seminal paper published by Ronald H. Coase in 1960 relied on the idea that harm was symmetric and, therefore, causation was misleading.[11] Coase's idea was that *if* tort laws aim at maximizing the social welfare—assuming evaluation of social welfare is possible—causation issues are irrelevant. The only thing to do is to compare the different activities (injuring and injured activities) from the point of view of efficiency. And the main social role played by tort law is to allocate the respective rights.[12] Many law and economics models, including those about multiple tortfeasors, agree with Coase and focus on efficiency, incentives, deterrence and maximization of welfare.[13]

Our approach is different from these models that are based on incentives and deterrence.[14] We use another branch of economic theory, named

ed to the damage." *See also* RESTATEMENT (SECOND) OF TORTS NEGLIGENT CONDUCT AS NECESSARY ANTECEDENT OF HARM § 432(2) (AM. LAW INST. 1965).

10. *See* Fischer, *supra* note 2, at 317 ("While I applaud the use of devices such as the but-for test and the NESS test to clarify our thinking about cause, I cannot believe we will ever be able to develop a mechanical test that will satisfactorily resolve difficult issues such as those discussed in this article."); *see* Peaslee, *supra* note 5, at 1131 ("Logic does not always have the last word in the law."). For similar ideas in France, see Boris Starck, *La pluralité des causes de dommages et responsabilité civile*, JCP 1970, I, 2339, 13: "Dans ce domaine, il n'existe aucun critère concevable pour apprécier l'influence causale de divers facteurs ayant contribué à provoquer le dommage." ("On this issue there is no conceivable criteria to evaluate the causal influence of several factors that brought about harm.").

11. R. H. Coase, *The Problem of Social Cost*, 3 J. L. & ECON. 1 (1960). Robert D. Cooter asks: "[h]ow is legal cause imbedded in formal models? Do the formal models clarify difficult legal issues about causation, as concluded by such writers as Calabresi, Shavell, and Landes and Posner? Is the disappearance of 'cause' from the formal models evidence of scientific progress and a reason for celebration, as Russell's views suggest? Or do the formal models obscure legal cause and suppress interesting legal issues, as asserted by critics such as Wright?" Robert D. Cooter, *Torts as the Union of Liberty and Efficiency: An Essay on Causation*, 63 CHI.-KENT L. REV. 523, 523–24 (1987). For Posner and Landes, "[m]uch of the scholarly literature on the subject, including that part of the literature which takes an explicitly philosophical approach to questions of causation, is devoted to trying to define 'cause' and then to fit the cases to the definition. The principal result of these efforts has been a negative one: to show that the notions of causation used in tort cases cannot be reduced to a single concept, whether necessary conditions, or sufficient conditions, or necessary and sufficient conditions." Landes & Posner, *supra* note 1, at 109 (footnote omitted).

12. Coase, *supra* note 11, at 15.

13. One of the rare papers dealing with Coase, causation and cooperative game theory is Varouj A. Aivazian & Jeffrey L. Callen, *The Coase Theorem and the Empty Core*, 24 J. L. ECON. 175, 175 (1981).

14. In economics, constant attention has been devoted to this topic. *See* John Borgo, *Causal Paradigms in Tort Law*, 8 J. LEGAL STUD. 419, 424 (1979); Landes & Posner, *supra* note 1, at 111; Mario J. Rizzo & Franck S. Arnold, *Causal Apportionment: Reply to the Critics*, 15 J. LEGAL STUD. 219, 219 (1986); Lewis Kornhauser & Richard L. Revesz, *Sharing Damages Among Multiple Tortfea-*

cooperative game theory, which deals with the properties of the rules to share a benefit or a cost resulting from a common activity between individuals. Cooperative game theory seems particularly appropriate to deal with causation issues in the law because the concepts of subsets of players and contributions are the cornerstone of this approach and are relevant as applied to causation issues.

This idea has already been developed in philosophy by Martin van Hees and Matthew Braham to characterize "degrees of causation".[15] We follow these authors but we provide a more operational view for the law. We will see that applying cooperative game theory concepts highlights some of the paradoxes associated with overdetermined causation cases.

The language of game theory—coalition, sets, minimally sufficiency sets, contribution—is relevant to the law. This article also intends to provide a unified approach on overdetermined causation cases: first, the same model is used to cover most of the overdetermined causation cases; second, the deep relationships between different criteria of causation are made clearer by the language of game theory[16]; and third, causation criteria and sharing rules used to divide the damage among tortfeasors involved are analyzed in a unique framework.

The remainder of the article is organized as follows. Section two provides examples of overdetermined causation cases to provide a typology of the different situations covered. Section three defines "overdetermined causation games." The concepts of players (individuals), coalitions of players, and characteristic functions are introduced in the circumstances of multiple causation. It then studies the general properties of these games. Section four develops the concept of a player's contribution to a coalition, including the grand coalition which joins all the tortfeasors. This section demonstrates that saying "a player has not been a necessary cause"—that is to say that the harm would have occurred even if he had not acted tortious-

sors, 98 YALE L.J. 831, 831 (1989); Francesco Parisi & Ram Singh, *The Efficiency of Comparative Causation*, 6 REV. L. ECON. 219 (2010); Robert Young et al., *Multiple Tortfeasors: An Economic Analysis*, 3 REV. L. & ECON. 111 (2007).

15. *See* Martin van Hees & Matthew Braham, *Degrees of Causation*, 71 ERKENN 323 (2009). We have already shown that such an approach could be fruitful to handle multiple causation. *See* Pierre Dehez & Samuel Ferey, *How to Share Joint Liability: A Cooperative Game Approach*, 66 MATHEMATICAL SOC. SCI. 44 (2013); Samuel Ferey & Pierre Dehez, *Multiple Causation, Apportionment and the Shapley Value*, 45 J. LEGAL STUD. (forthcoming 2016).

16. *See* Robert J. Aumann, *What is Game Theory Trying to Accomplish*, *in* FRONTIERS OF ECONOMICS 7 (K. Arrow & S. Honkapohja eds., 1985) ("This brings us to the second component of comprehension, which is really part of the first: unification. The broader the area that is covered by a theory, the greater is its 'validity'. I am not thinking of 'validity' in the usual sense of truth, but rather in the sense of applicability or usefulness[.]").

ly—is not equivalent to saying that "his contribution is zero."[17] In other words, there is room to consider both that a tortfeasor (i) has positively contributed to the damage and (ii) has not been a necessary condition. Section four insists on the Shapley value as a relevant evaluation of the contribution of a player to the game. The Shapley value is consistent with the NESS criteria. However, as this article insists on an evaluation of the individual contribution to the final damage, those interested in partial causation based on contribution may be convinced. Lastly, this evaluation could be a benchmark to apportion damage between tortfeasors in the case of several and joint liability when one tortfeasor has completely paid the victim and has a claim against the other tortfeasors to get its shares back. Section five concludes. The findings of the article leave room for considering other sharing rules and comparing their results and properties with the Shapley value.

II. OVERDETERMINED CAUSATION CASES: EXAMPLES AND PARADOXES

Overdetermination is a general category under which several kinds of cases may be subsumed. In the legal literature and sources, other terms referring to more or less the same issue are used: "multiple sufficient causes," "preemption" or "preemptive causes," "additional causes,"[18] "competing causes,"[19] "concurrent causes,"[20] "duplicative-causation,"[21] "insufficient causes,"[22] "unnecessary causes," "threshold cases,"[23] or "cumulative sources of harm."[24] These categories may refer to different hy-

17. This is all the more interesting because our approach builds a bridge between the but-for test, the NESS test and contribution. See the criticism from the *Restatement (Third)* against the *Restatement (Second)* about the "substantial factor" test which assumes an evaluation of the causal strength of the tortious act. RESTATEMENT (THIRD) OF TORTS: LIABILITY FOR PHYSICAL AND EMOTIONAL HARM § 36 cmt. a (AM. LAW INST. 2010).

18. HART & HONORÉ, *supra* note 1, at 235 ("[W]e deal with additional causes, i.e. with cases in which there are present on a given occasion two or more factors each sufficient with other normal conditions to bring about certain harm."). See *also* RESTATEMENT (THIRD) OF TORTS: LIABILITY FOR PHYSICAL AND EMOTIONAL HARM § 27 cmt. a (AM. LAW INST. 2010).

19. *Id.* "This Section applies whenever there are two or more competing causes, each of which is sufficient without the other to cause the harm and each of which is in operation at the time the plaintiff's harm occurs." *Id.*

20. *See* PRINCIPLES OF EUROPEAN TORT LAW art. 3:102 (2005).

21. Wright, *supra* note 1, at 1791.

22. Fischer, *supra* note 2, at 277.

23. Stapleton, *supra* note 9, at 39.

24. Miller, *supra* note 7, at 327.

potheses, scenarios, and cases,[25] but they share a common property: that one or several tortfeasors will not be considered a cause under the but-for-test because their tortious act is not necessary (i.e., even if they had acted non-tortiously, the harm would have still occurred). This section gives some examples and cases and explores the paradoxes raised. In all the following, we use the traditional legal definition of the but-for-test.

A. Multiple Sufficient and Unnecessary Causes (Rosaria and Vincenzo Fires)

The first example is the simplest. It deals with multiple sufficient causes and is well illustrated by the two-fire case.[26] In that case, two fires negligently and independently lit by two people merge and destroy the property of the victim. Neither of the two tortious acts are a necessary condition for the harm in the sense that if one of the tortfeasors had not lit his fire, the harm would have still happened. In other words, neither of the two fires was necessary but both were sufficient. The strict application of the but-for test would exonerate both of them—a result that is uncomfortable. Here is an example of duplicative causation and is the first category of overdetermined causation cases.

B. Multiple Sufficient Causal Sets: Unnecessary and Non-sufficient Conditions (Paul's Car)

The second case, "Paul's car," following the illustration provided by the *Restatement*,[27] changes the previous example by assuming that tortious activities are neither necessary nor sufficient:

> Able, Baker and Charlie, acting independently but simultaneously, each negligently lean on Paul's car, which is parked at the lookout at the top

25. *See, e.g.*, Wright, *supra* note 1, at 1791–1801 (discussing the Hart and Honoré typology). "Perhaps as a result of their confusing typology, Hart and Honoré lose sight of the basic concept of causation embodied in the NESS test." *Id.* at 1797.

26. *See* Fischer, *supra* note 2, at 280. *See also* RESTATEMENT (THIRD) OF TORTS: LIABILITY FOR PHYSICAL AND EMOTIONAL HARM § 27 cmt. a (AM. LAW INST. 2010) ("Rosaria and Vincenzo were independently camping in a heavily forested campground. Each one had a campfire, and each negligently failed to ensure that the fire was extinguished upon retiring for the night. Due to unusually dry forest conditions and a stiff wind, both campfires escaped their sites and began a forest fire. The two fires, burning out of control, joined together and engulfed Centurion Company's hunting lodge, destroying it. Either fire alone would have destroyed the lodge. Each of Rosaria's and Vincenzo's negligence is a factual cause of the destruction of Centurion's hunting lodge.").

27. *See* Carpenter, *supra* note 5, at 948. Stapleton illustrates this by the bridge example. Stapleton, *supra* note 9, at 43 ("No individual was necessary for the destruction of the car, yet, it seems plausible that the law would want to identify their role. If the law required a factor to satisfy the but for test before it would be recognized as a factual 'cause' the striking result would be that the law would not identify any of these three individuals as a 'cause' of the car's destruction.").

> of a mountain. Their combined force results in the car rolling over a diminutive curbstone and plummeting down the mountain to its destruction. The force exerted by the push of any one actor would have been insufficient to propel Paul's car past the curbstone, but the combined force of any two of them is sufficient.[28]

Here too, the but-for test seems to be inappropriate and leads to exoneration of the three tortfeasors because none are necessary. But, dealing with those cases is different from the two fires example; contrary to that case, neither of the tortious acts is sufficient. There are only sets of tortious conduct that are sufficient to actually cause the harm. The *Restatement* clearly recognizes this feature and refers to "multiple sufficient causal sets." These cases have motivated legal scholars to find another criteria of causation. The NESS test advocates that A is a factual cause of the harm because it is possible to find a set of torfeasors including A which is sufficient to cause the harm and where A is a necessary element of this set. The set $\{A,B\}$ is sufficient to destroy the car and kill the passenger and, at the same time, removing A from the set $\{A,B\}$ leads to no harm. A is a necessary element of a sufficient set.[29]

C. Unnecessary Causes: One is Sufficient, the Others Are Not (Bridge)

The two previous cases do not cover all the overdetermined causation cases. More subtle and complex cases, which are not properly handled by the dichotomy "unnecessary and sufficiency" or "unnecessary and no sufficiency," are easy to imagine. The "threshold cases" described by Stapleton are cases of this type.

Assume a bridge carrying a train line was built to withstand a weight below sixteen units. The train weighs ten units and the three tortfeasors place different weights on the bridge (A: six units; B: three units and C: three units). The train passes across the bridge, the bridge collapses and a passenger is killed. Now, A is unnecessary but sufficient, while B and C are

28. RESTATEMENT (THIRD) OF TORTS: LIABILITY FOR PHYSICAL AND EMOTIONAL HARM § 27 cmt. f, illus. 3 (AM. LAW INST. 2010). Stapleton, *supra* note 9, at 47–48 ("On a certain train line the trains weigh 10 units each; a bridge carrying the line was built to withstand a weight of 20 units. A train will pass across the bridge at noon. Before noon X deposits a weight of 6 units within the bridge structure, then Y deposits another 6-unit weight, then Z deposits another 6-unit weight. X, Y and Z act independently and are unaware of the conduct of each other. At noon the train attempts to cross the bridge which collapses, killing a passenger on the train.").

29. Miller states an important point about the NESS test: "Central to Wright's approach (and contrary to that of many legal scholars in this area) is the assertion that it is possible to construct a causal account of a set of events (leading to a harmful outcome) which is independent of those considerations by which an agent of these events might be deemed legally liable." Miller, *supra* note 7, at 323.

unnecessary and not sufficient. The but-for test would reach a solution where no tortfeasor would be liable. At the same time, the NESS test would say that the three tortious conducts are factual causes of harm (there exists at least one set where *A*, *B* and *C* are necessary for the sufficiency of the set).[30]

But the NESS test gives little information about the respective degrees of causation and the causal contributions of each of the tortious acts. Agent *A* could be said to have had a more important causal power or contribution than *B* or *C*.[31] Activity *A* is sufficient while the other ones are not, so is it meaningful to consider that *A* has had a more important causal power than *B* or *C*? It appears that Hart and Honoré address this issue when they refer to "degrees of causation."[32] In other words, this example raises the issue of whether apportionment among tortfeasors should be done on the basis of their causal contributions to the harm. Our model will deal with this issue in section three.

D. Non-sufficient Causes: One is Necessary and the Other is Not (Pollution)

The typology in terms of necessary and sufficient causes leads to other possible cases mixing a necessary cause with an unnecessary one, both being non-sufficient. An example is the case where multiple firms have caused damage by simultaneously pouring amounts of a toxic substance into a lake and where no single firm could cause the damage alone. Imag-

30. RESTATEMENT (THIRD) OF TORTS: LIABILITY FOR PHYSICAL AND EMOTIONAL HARM § 27 cmt. f (AM. LAW INST. 2010) ("Moreover, the fact that the other person's conduct is sufficient to cause the harm does not prevent the actor's conduct from being a factual cause of harm pursuant to this Section, if the actor's conduct is necessary to at least one causal set. Sometimes, one actor's contribution may be sufficient to bring about the harm while another actor's contribution is only sufficient when combined with some portion of the first actor's contribution. Whether the second actor's contribution can be so combined into a sufficient causal set is a matter on which this Restatement takes no position and leaves to future development in the courts.").

31. This point is recognized in the RESTATEMENT (THIRD) OF TORTS: LIABILITY FOR PHYSICAL AND EMOTIONAL HARM § 27 cmt. g (AM. LAW INST. 2010)

32. *See* HART & HONORÉ, *supra* note 1, at 233 ("Can a meaning be attached to 'degrees of causation'? There are some indications in ordinary speech that it can. An event is often, outside the law, said to be caused partly by one factor and partly by another, or more by one thing than another, or mostly by a particular factor. If then, 'degrees of responsibility' are to be interpreted in causal terms the most rational basis for apportionment becomes the relatively dangerous character of the acts of the various tortfeasors."); *see also* van Hees & Braham, *supra* note 15, at 325: ("The meaning attached to "substantial factor" is close. Given the practical demand, can any factual content be given to the notion of degrees of causation? One prominent answer, which is the one that Hart and Honoré (1959, p. 233ff) provided in their seminal monograph *Causation in the Law* is to say that the concept, while valid, is inescapably vague with its substance being provided by attributive terms of ordinary language. That is, 'degrees of causation' is captured by locutions such as the 'chief' or 'main' or 'principal' cause, or of 'more important', 'effective' or 'potent' causes.").

ine now that the victim raises salmon in a pond on his property.[33] Three firms, identified as 1, 2 and 3, negligently poison this pond by pouring dangerous chemicals. Assume a threshold exists, say seventy-five units, above which the concentration of chemicals becomes lethal for salmon. Assume that firm 1 has poured fifty units while firms 2 and 3 have poured thirty units each.[34] Firm 1's tortious act is necessary but not sufficient while firm 2's tortious act is neither unnecessary nor sufficient. And the same applies to firm 3.

Applying the but-for test, courts would declare firm 1 liable and exonerate firms 2 and 3, despite the fact that firm 1 alone would not have exceeded the threshold.[35] Illustration 4 in the *Restatement* belongs to this category when it states "*that there are common elements in each of the sufficient causal sets does not prevent each of the sets from being a factual cause pursuant to this Section*."[36] At the same time, compared to the previous example, common sense would say that firm 1 is "more causally" involved than the other two firms.

E. Non-sufficient Necessary Causes and Sufficient Unnecessary Cause (Push/Pull Car)

The last type of example is less likely to happen and implies what Hart and Honoré call "neutralizing causes."[37] Such cases shall not exist with two players because it is impossible and contradictory for *A* to be necessary and non-sufficient and for *B* to be unnecessary and sufficient at the same time. However, with three tortfeasors (*A*, *B* and *C*), such a structure may appear. It would be the case in the Paul's car example if *A* is not strong enough to move the car by himself while *B* and *C* are strong enough. Imagine that *A*

33. *See* Wright, *supra* note 1.

34. The same structure would be obtained by changing the Paul car's example and assuming that one of the three tortfeasors would be stronger than the others but not strong enough to push the car by himself. If he needs the help of only one of the two others, this tortfeasor is a wrongdoer who belongs to all the sufficient sets that bring about the harm.

35. *See* RESTATEMENT (THIRD) OF TORTS: LIABILITY FOR PHYSICAL AND EMOTIONAL HARM § 27 cmt. g (AM. LAW INST. 2010) ("When a person contracts a disease such as cancer, and sues multiple actors claiming that each provided some dose of a toxic substance that caused the disease, the question of the causal role of each defendant's toxic substance arises. Assuming that there is some threshold dose sufficient to cause the disease, the person may have been exposed to doses in excess of the threshold before contracting the disease. Thus, some or all of the person's exposures may not have been but-for causes of the disease. Nevertheless, each of the exposures prior to the person's contracting the disease (or the time at which the disease was determined, see § 26, Comment *k*) is a factual cause of the person's disease under the rule in this Section.").

36. *Id.* at cmt. f.

37. *See* HART & HONORÉ, *supra* note 1, at 239 (giving the example that "[a] negligently sets a fire which would have been sufficient to destroy C's house but, before the fire reaches C's house, it is quenched by the waters which B has negligently allowed to escape from a dam. . . .").

and *B* have pushed the car while *C* has pulled it. Suppose that a force of 10—in any direction—is enough to move the car and destroy it and that *A* exerts an external force on the car up to 5, *B* up to 20 and *C* exerts an opposite force up to 15. In that situation, *B* alone (or C alone) would have destroyed the car, (so *B* or C is sufficient but not necessary) but *B* and *C* taken together do not bring about any harm (because one pulls the car while the other pushes it), so *B* and *C* are neutralizing causes. It is because *A* participates in the common activity and adds a small and marginal push that the car actually falls into the ravine (so *A* is not sufficient but necessary, as well).[38]

To conclude, Table 1 summarizes different situations implying necessary and unnecessary causes, sufficient causes and non-sufficient causes. We restrain our table to two potential causes (*A* and *B*) for more simplicity. Several remarks should be made. First, the table is symmetric and all the combinations are not possible (for example two different causes cannot be "necessary and sufficient"). Second, some combinations are impossible with two players but become possible with three. This is illustrated by both the Paul's car and push/pull cases. Third, the case implying two necessary and no sufficient causes is excluded because it is not an overdetermined causation case. In this way, the table covers all types of overdetermined causation cases.

Table 1. Overdetermined causation case: a typology

			A			
			Necessary		**Not Necessary**	
			Sufficient	**Not Sufficient**	**Sufficient**	**Not Sufficient**
B	**Necessary**	**Sufficient**	Impossible	Impossible	Impossible	Trivial
		Not Sufficient	Impossible	Excluded	Push/pull car	Pollution
	Not	**Sufficient**	Impossible	Push/pull car	Two fires	Bridge

38. Under these assumptions, *C* (resp. *B*) is a sufficient and unnecessary cause. The same structure would take place in some case of preemptive causation where the consequences of an act are neutralized by the consequences of another act. *See* RESTATEMENT (THIRD) OF TORTS: LIABILITY FOR PHYSICAL AND EMOTIONAL HARM § 27 cmt. i (AM. LAW INST. 2010).

	Necessary	**Not Sufficient**	Trivial	Pollution	Bridge	Paul's car

III. OVERDETERMINED CAUSATION GAMES

This section elaborates on cooperative game theory developed in economics to handle overdetermination issues in the law. Intuitively, we argue that people have acted together to bring about the harmful consequences. We do not mean that they jointly acted on purpose but only that their joint acts have had a consequence—the harm suffered by the victim denoted d (d is the monetized damage to be paid by liable parties to the victim). The first step of the model is to formally "describe" the data of the case. The second step is to characterize the individual contribution of each player to the common result d. The third step is to analyze how to share the liability among the players.

We provide a model in order to capture the essential features of overdetermined causation cases. First, "liability games" are formally defined. The concepts of grand coalition and sub-coalitions in relation to the law are presented and discussed. Second, this section deals with the marginal contribution concept in order to characterize necessity, sufficiency and the but-for test in terms of *individual contribution* to a coalition. The main finding of this section is to demonstrate that cooperative game theory is relevant to better understand causation issues in the law, and it allows for better characterizing what the law refers to as "sufficient," "sufficient sets," "multiple sufficient causes," or "but-for test."

A. Definitions of Overdetermined Causation Games: Coalition and Causation

We consider a case involving multiple tortfeasors. Contrary to many law and economics models considering causation from an *ex ante* perspective, we consider causation issues from an *ex post* perspective, once the harm has occurred. We assume that courts are able to monetize the harm suffered by the victim. The set of the tortfeasors involved in the case is denoted by N ($n \geq 2$). Tortfeasors are called the players of the game; the three people negligently pushing Paul's car are the set of players in example 1, the three polluters negligently polluting the stream are the set of players in example 4, etc. We do not assume that they should be held to be a factual cause but only that they are involved in the case.

To formalize this idea, let us assume that n injurers have been involved, $n \geq 2$. Each injurer is identified by an index i running from 1 to n. We consider all possible subsets of the set $N = \{1,. . .n\}$ of all injurers and we denote by $v(S)$ the potential damage of subset S.[39] The potential damages $v(S)$ are all hypothetical, except $v(N)$, which is nothing but the actual damage suffered by the victim that must be divided between the injurers.

In this way, we construct a "*characteristic function*" v that associates a number to each subset of N. Formally, the couple (N,v) is a *cooperative game with transferable utility*.[40] Here, injurers are "players," subsets of injurers are "coalitions" and potential damages are coalitions' worth. The toolbox of the theory of cooperative games can then be used. Here, we shall use the Shapley value, a well-known allocation rule introduced by Lloyd Shapley in 1953, based on the notion of *marginal contribution*.[41]

In a general context, $v(S)$ is the "worth" of coalition S which measures the minimum that coalition S can ensure by itself, if it forms. In our context, $v(N)$ has to be considered as an actual and observable event—the actual result from the tortious acts of all the players involved. On the contrary, $v(S)$ with S a proper subset of N, should be interpreted as a counterfactual situation, i.e., the harm that would have occurred if the players outside S had not acted tortiously.[42] In the Paul's car example, $v(AB)$ is the harm brought about by A and B pushing the car, assuming that C did not push the car;[43] $v(A)$ is the harm brought about by the behavior of A (A's push) in the hypothetical circumstances where B and C have not pushed the car.[44] In our example, A is not strong enough to move the car by himself; consequently, in that hypothetical situation, the harm would not have occurred and $v(A) = 0$.[45]

39. The empty set $\varnothing$ is a subset and, by convention, $v(\varnothing) = 0$. The empty set refers to the "normal course of events" assuming that no tortious act occurs by any players. The harm in that hypothetical state of the world is normalized to zero.

40. Transferable utility games introduced by JOHN VON NEUMANN & OSKAR MORGENSTERN, THEORY OF GAMES AND ECONOMIC BEHAVIOR (Princeton Univ. Press, 3d ed. 1953) (1944).

41. Contrary to van Hees and Braham, *supra* note 15, who insist on power index, we argue that the Shapley value needs to be considered to assess the causal contribution.

42. Fischer criticizes the NESS test by using a splitting argument. Fischer, *supra* note 2.

43. The worth of a coalition $\{A,B\}$ should be noted $v(\{A,B\})$. For simplicity, we write $v(\{A,B\}) = v(AB)$.

44. For simplicity, our approach is dichotomous: we deal with two types of actions ("push" or "not push") but it would be possible to introduce more subtle actions as "a weak push," a "strong push," etc. Similarly, only two states of the world are considered here (damage occurs or not). What matters is the possibility to associate a value to every coalition.

45. The important point is that the characteristic function does not make a specific hypothesis on causation between players and harm. Indeed, we could add a fourth player, D, named Smith, who, at the same time that Paul's car was pushed in the ravine, drove too fast on a highway far away. D acted

With two tortfeasors, there are 3 coalitions: {1}, {2}, {1,2}. With three tortfeasors, there are 7 coalitions : {1}, {2}, {3}, {1,2}, {1,3}, {2,3}, {1,2,3}.[46] The function v associates to each coalition the harm it brings about. In the following, we illustrate the formal concept with cases presented in section two. See, for example, the "pollution game." The set of tortfeasors is $N = \{1,2,3\}$ and the associated characteristic function v is given by:

$$v(1) = v(2) = v(3) = 0$$
$$v(12) = v(13) = d$$
$$v(23) = 0$$
$$v(123) = d$$

By analogy with a voting process, it could be said that firm 1 has a veto; without firm 1, damage would not occur.

B. Marginal Contributions and Causation Criteria

The originality of cooperative game theory lies in the concepts of coalition and worth of a coalition. This is particularly relevant for multiple causation cases. Indeed, we are able to measure the change in the worth of a coalition when adding or removing a player from that coalition. This is captured by the notion of individual *marginal contribution* of a player to any coalition S. Formally, the marginal contribution of player i to coalition S is defined by:

$$Cm_i(S) = v(S) - v(S \setminus i)$$

It is the difference between the worth of coalition S and the worth of coalition S without player i (a difference which is of course equal to zero when i is not included in S). We argue that it is accurate, relevant and fruitful to describe some of the most common legal causation concepts used by scholars, such as the but-for test, NESS test or necessity/sufficiency dichotomy, in terms of marginal contributions.

Consider first necessity in the legal sense of the but-for test. A player i is said to be *necessary* to a coalition S *if and only if* removing player i from S leads to decrease its worth from d to zero:

tortiously and could be added as a player of Paul's car game but he will be a nul player because he never changes the value of any coalition regarding the car destruction.

46. For n players, there are 2^n–1 coalitions. The order of players has no importance, the coalitions {1,2} and {2,1} are the same.

$$Cm_i(S) = d$$

From this point of view, the necessity requirement of the but-for test proceeds by comparing the state of the world that occurred where *i* has tortiously acted with a hypothetical state of the world without *i*'s act, assuming the other tortfeasors have tortiously acted. In formal terms, a player will be said necessary according to the but-for test *if and only if* he is necessary to the grand coalition *N*:

$$Cm_i(N) = d$$

It should be noticed that the but-for test does not take into account the marginal contributions to sub-coalitions. In the two fires example, none of the tortfeasors could be said necessary because their contribution to the grand coalition is zero. Remove player 1 (resp. player 2) from the subset {1,2}—i.e., compare the state of the world with player 1 (resp. 2) and the state of the world without player 1 (resp. 2):

$$Cm_1(N) = v(1,2) - v(2) = 0$$

$$Cm_2(N) = v(1,2) - v(1) = 0$$

A torfeasor is said to have been sufficient for the occurrence of the damage *if and only if* his individual marginal contribution is equal to the harm *d*:

$$Cm_i(i) = v(i) = d$$

Such a definition can be extended to coalition. A coalition is sufficient if its worth is equal to *d*. A subset *S* of tortfeasors will be said "*minimally sufficient*" *if and only if* the marginal contributions of all the players in *S* equal *d*. The players are consequently necessary to the sufficiency of this coalition. The concept of minimally sufficient is in line with the NESS test. In the bridge example, {1,2}, {1,3} and {2,3} are minimally sufficient subsets.

C. Characterizing Overdetermined Causation Cases

The concept of marginal contribution helps in characterizing overdetermined causation cases. They are games (N,v) where the marginal contri-

bution to the grand coalition is zero for at least one non nul player.[47] Table 2 lists the different cases in terms of marginal contributions.

Table 2. Overdetermined causation case: marginal contributions, necessity and sufficiency

			A		
			Necessary $Cm_A(N) = d$	**Not Necessary** $Cm_A(N) = 0$	
			Not Sufficiency $Cm_A(\mathrm{A}) = 0$	**Sufficient** $Cm_A(\mathrm{A}) = d$	**Not Sufficient** $Cm_A(\mathrm{A}) = 0$
B	**Necessary** $Cm_B(N) = d$	**Not Sufficient** $Cm_B(B) = 0$	Excluded	Pull/Push car	Pollution
	Not Necessary $Cm_B(N) = 0$	**Sufficient** $Cm_B(N) = d$	Pull/Push car	Two fires	Bridge
		Not Sufficient $Cm_B(B) = 0$	Pollution	Bridge	Paul's car

47. A player who never contributes is a nul player. His marginal contributions are all equal to zero.

The failure of the but-for test is better understood. Mathematically, nothing prevents marginal contribution to the grand coalition from being zero for all the players. This is not the same thing as considering that *global* contribution is zero. The main criticism this article attributes to the but-for test is that it is too restrictive; it considers only the contributions to the grand coalition. However, the effective contribution of a player to the final result lies not only on his contribution to the grand coalition but also on his contributions to the intermediate coalitions. In the Paul's car example, the marginal contribution of player 1 to the grand coalition is zero precisely because coalition {2,3} already has a positive worth. In other words, it is because players 2 and 3 have already together caused the harm that player 1 provides no additional harm to this coalition. Obviously, what could be said about player 1 is also true for players 2 and 3. An appropriate causation criterion should take account of this property. Regarding this issue, the NESS test is superior because it takes into account all the sufficiency sets (including intermediate coalitions). This leaves room for evaluating the "degree of causation" or the causal influence of an activity on the occurrence of the harm, and the Shapley value appears to be an interesting and useful benchmark for this evaluation.

IV. CAUSATION, CONTRIBUTION AND THE SHAPLEY VALUE

We have shown that the classical concepts of the cooperative game theory are relevant to analyze the law. The next step is to deal with the best apportionment of liability among tortfeasors.

A. Sharing Rules and Apportionment

The multiple causation cases lead to a practical difficulty: how to share the damage to be paid to the victim among the tortfeasors involved. In most of the cases, the victims have a right to be fully compensated for their loss and the shares of each torfeasor need to be determined. This is the case of joint and several liability.[48] The *Third Restatement* advocates a two-step process: first, apportionment by causation and second, apportionment by responsibility.[49] However, some argue that operationalizing that two-

48. In most cases involving multiple tortfeasors, plaintiffs can sue the defendants jointly or separately and the law allows for contribution among joint tortfeasors. *See* Michael Faure, *Attribution of Liability: An Economic Analysis of Various Cases*, 91 CHI.-KENT L. REV. 101, 104–07 (2016).

49. For an analysis of the two step process in terms of the Shapley value applied to successive injuries ("sequential liability games"), see Dehez & Ferey, *supra* note 15.

step process in overdetermined causation cases is quite complicated. For Michael D. Green, asbestos litigation illustrates the difficulty:

> Assessing causal roles in asbestos gets into some of the knottiest causal problems in tort law: Consider two of the most interesting, yet perplexing: First, suppose that for a plaintiff to contract lung cancer, a threshold dose, say 100 units of asbestos exposure is required. Suppose that defendant has been exposed to 105 units of asbestos by 21 defendants, each providing 5 units of exposure. Each one can claim that it was not a but for cause of the harm because absent its asbestos, the plaintiff still would have contracted lung cancer. This is the toxic substances analog of the classic problem of two independently set fires, each of which would have burned down the plaintiff's house at the same time. Courts have, uniformly in the case of two tortfeasors who set the fires, held them both liable, employing the 'substantial factor' rubric of the Second Restatement.[50]

The example is the same as Paul's car of our typology and has the same structure as the pollution case where each polluter pours fifty units of toxic substances in a lake with a threshold of 100 units. No apportionment on causal basis seems to be implemented, at least when the but-for test is used. This is the consequence of the but-for test's restrictiveness: the but-for test takes into account only the marginal contribution to the grand coalition. Another approach is possible: assessing the causal contribution taking into account the marginal contributions to all coalitions. This is precisely what the Shapley value does. In the remainder of the section, we explain why the Shapley value can be used to evaluate the causal contribution of each of the tortfeasors.

B. The Shapley Value: Formula and Applications

An injury has been caused by several actors (injurers or tortfeasors). The problem is to specify a division of the resulting damages among the injurers. Our idea is to base the division on "marginal damages." The Shapley value allocates $v(N)$, the worth of the "grand coalition" N (which is also the value of the damage to be paid and shared among tortfeasors), on the basis of players' contributions to *all* coalitions, not only on the basis of their contributions to N.

50. Michael D. Green, *Second Thoughts About Apportionment in Asbestos Litigation*, 37 SW. U. L. REV. 531, 535 (2008). For a similar view, see Miller, *supra* note 7, at 337; *see* Green ("Does it matter if, instead of 21 defendants, there are two—one who provides 100 units, sufficient by itself to cause the disease, while the second defendant provides five units? The second problem occurs when other defendants provide 105 units and the 22nd defendant contributes but one-tenth or even one-hundredth of a dose, a trivial dose. This gets to the frequency, regularity, and proximity requirement that many states have imposed, which sets a threshold of involvement before a defendant can be found a cause at all.").

The Shapley value is defined as a weighted average of players' marginal contributions:

$$SV_i(N,v) = \sum_{S \subset N} \frac{(n-s)!\,(s-1)!}{n!}\Big(v(S) - v(S \setminus i)\Big) \quad i = 1,\ldots,n$$

where the weights depend on coalition size.[51]

The Shapley value provides an evaluation of the contribution of each player to the final result while taking account of their individual marginal contributions to all the coalitions. As such, it is a formula. However, it is based on desirable properties that an allocation rule should possess.[52] Let us consider a simple case (Paul's car) involving three players:

$v(1) = v(2) = v(3) = 0$
$v(1,2) = v(1,3) = v(2,3) = d$
$v(1,2,3) = d$

This is a symmetric game; all players are equal and the Shapley value allocates an identical amount to each player. This is confirmed by the following table:[53]

	$i = 1$	$i = 2$	$i = 3$	weight
$S = \{2,3\}$	d	0	d	1/6
$S = \{1,2\}$	d	0	d	1/6
$S = \{1,3\}$	d	0	d	1/6
$S = \{1,2,3\}$	0	0	0	1/3

Applying formula (*), the Shapley value indeed reduces to the equal division allocation: $SV_1 = SV_2 = SV_3 = d/3$. The three players would be exonerated if the but-for test were applied; their marginal contribution to the grand coalition is indeed zero. The Shapley value provides an alternative apportionment and assesses that all have contributed one third to the victim's loss. Each player is present in two subsets that cause the loss. They

51. We use lowercase letters to indicate subsets' sizes: $n = |N|$, $s = |S|$ . . . .
52. See Dehez & Ferey, *supra* note 15, for details on axiomatizations of the Shapley value.
53. Only the coalitions with non-zero worth are listed.

are in a symmetric situation and the result is quite natural. It could be said that the Shapley value is consistent with the NESS test insofar as the 2-player sets {1,2}, {2,3} and {1,3} are sufficient and each of the players are necessary elements of these sufficient sets.

Let's consider another example: the pollution game. The resulting potential damages are given by:

$v(1) = v(2) = v(2,3) = 0$
$v(1,2) = v(1,3) = v(1,2,3) = d$

Here, the marginal contributions are different from the previous case because 1 is a necessary (but not sufficient) element. The following table gives the associated marginal damages.

	$i = 1$	$i = 2$	$i = 3$	weight
$S = \{2,3\}$	0	0	0	1/6
$S = \{1,2\}$	d	d	0	1/6
$S = \{1,3\}$	d	0	d	1/6
$S = \{1,2,3\}$	d	0	0	1/3

Applying formula (*), the Shapley value reduces to the following allocation of damages d:

$SV_1 = 2/3d$

$SV_2 = SV_3 = 1/6d$

Injurer 1 supports 2/3 of damages d and the remaining third is allocated equally between injurers 2 and 3. They are indeed "equal."[54] The Shapley value recognizes the role played by injurers 2 and 3. They have contributed to the harm insofar as they are necessary elements of a sufficient set to bring the harm about. The Shapley value is an interesting shar-

54. If instead only the marginal contributions to the grand coalition, $v(N) - v(N \backslash i)$, were taken into account (the but-for test), we would end up with a division of damages that imposes that injurer 1 pay for the entire damage, a division that could hardly be considered fair.

ing rule that takes into account the facts that, first: player 1 is a necessary element (1 is present in the three sets of tortfeasors which bring about the harm), but second: player 1 is not a sufficient element (it is necessary that either 2 or 3 joins 1 to cause the harm). That is why player 1 has not fully compensated the victim on his own (1 is not a necessary and sufficient cause); 2 and 3 have to pay a share of the damage. The Shapley value is one of the sharing rules developed in cooperative game theory that seems consistent with the NESS test insofar as the Shapley value takes account of the marginal contribution of players on all the intermediate—and sufficient—sets (sub-coalitions) bringing about the harm.

C. Why the Shapley Value?

Another view of the Shapley value focuses on its properties. In cooperative game theory, these properties are called axioms. One of the most famous axiomatizations is attributed to Shapley[55] and states that the Shapley value follows four axioms: the first one is called efficiency; the second one is a nul player axiom; the third is a symmetric axiom; and the fourth is an additivity axiom. More precisely, it has been proved that the Shapley value is the only allocation rule that verifies these four axioms.

It is interesting enough to wonder whether these axioms (and their mathematical counterparts) have a meaning for the law. The first three axioms are quite obvious for the law. The first one states that the worth of the grand coalition is shared among players. This property implies that the entire damage, no more, no less, is paid to the victim by the tortfeasors. The second one is that a nul player (his contributions are zero for all coalitions) will not pay anything because he is not causal. The third one deals with equal treatment of equals regarding their participation in the harm (two symmetric players pay the same amount). The fourth axiom states that if a game G1 is the sum of two games G2 and G3 (G1=G2+G3), then the Shapley value calculated for each player and associated with G1 is the sum of the Shapley values associated with G2 and G3.

This last axiom is more difficult to interpret than the others, but this article insists on its meaning in the legal context. Indeed, according to us, the additivity axiom is in line with the principles advocated in the *Restatement* regarding apportionment of damage among tortfeasors.[56] The *Re-*

55. Lloyd S. Shapley, *A Value for n-person Games*, *in* CONTRIBUTIONS TO THE THEORY OF GAMES II 307–17 (Harold W. Kuhn & Albert William Tucker eds., 1953). There are several axiomatization of the Shapley value, starting with Shapley's original one.

56. *See* RESTATEMENT (THIRD) OF TORTS: APPORTIONMENT OF LIABILITY § 26 (AM. LAW INST. 2000).

statement explicitly insists on the fact that when harms are divisible—i.e., it is possible to divide the harm in several parts[57]—these parts should be considered separately in terms of apportionment. Regarding this issue, it could be thought that the best sharing rule be additive i.e., the same apportionment should be implemented by applying the sharing rule to the entire case or by applying the sharing rule separately to the different parts of the harm. It is precisely this result that the Shapley value leads to. The additivity property assures that the Shapley value leads to the same result. Let us imagine that three tortfeasors (A, B and C) pollute a lake by pouring toxic substances. Imagine that they destroy two fish farms, outcomes that cause two separate harms H1 and H2. But let us assume that the factfinder assesses that A and B would have been sufficient to cause H1 and B and C would have been sufficient to cause H2. Moreover, he demonstrates that A is far enough from the second fish farm and consequently has not caused any damage to farm 1 and C is far enough from the first fish farm and consequently has not caused any damage to farm 2.

What is the proper way to apportion damages in that case? Dividing harms by causation leads to dealing with H1 and H2 separately. The two "subcases" are overdetermined cases but A and B are involved in H1 and B and C are involved in H2. Applying an additive sharing rule makes sure that the amount of the compensation to be paid by A, B and C is the same whether the case is globally settled (H1 and H2 together) or the two cases are settled separately. This is a strong argument in favor of the Shapley value as a rule to apportion damages in the case of overdetermined cases.

V. CONCLUDING REMARKS

Causation is one of the most intricate and difficult issues in the law. In the present article, we provide an economic approach to multiple causation in the law focused on a specific set of cases, the overdetermined causation cases. This article holds three main ideas. First, the language and concepts of cooperative game theory—sets, coalition, contribution, solution concepts, sharing rules—are of great interest for legal scholars. They provide a formal approach to most of the legal concepts used in the literature such as "sufficiency set," the NESS test, contribution, and the but-for test. Second, this approach highlights the paradoxes raised by a strict application of the but-for test. These paradoxes rely on the fact that the but-for test focuses on the marginal contributions to the great coalition but does not take into account the causal contributions to intermediate coalitions. We have shown

57. Usually, a part of the harm is due only to one tortfeasor or to a subset of tortfeasors.

that a zero contribution to the grand coalition does not mean that a player has not causally contributed (the share of a tortfeasor determined by the Shapley value may be positive even if his contribution to the grand coalition is zero). There is a bridge between scholars advocating the use of the NESS test and the ones advocating contributive or substantial factor criteria. Third, our approach leaves room open for considering other sharing rules in order to solve the difficulty in apportioning damage in the case of multiple causation.