GOD'S DICE: THE LAW IN A PROBABILISTIC WORLD

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I. INTRODUCTION

"*Quantum theory has thus demolished the classical concepts of . . . strictly deterministic laws of nature*."[1]

The concept of causality is the cornerstone of scientific research, regardless of the field of study. In spite of countless attempts to oversimplify[2]

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[1] FRITJOF CAPRA, THE TAO OF PHYSICS: AN EXPLORATION OF THE PARALLELS BETWEEN MODERN PHYSICS AND EASTERN MYSTICISM 68 (1st ed. 1975).

[2] Causation has been described "as one of 'the simplest and most obvious' problems in determining tort liability . . . ." Richard W. Wright, *Causation in Tort Law*, 73 CALIF. L. REV. 1735, 1737 (1985); *see*

or to circumvent[3] the problem, the law is no exception. In this Article, I will try to continue the path taken by many legal scholars who attempted to lessen the gap between the concept of causation in natural sciences and its application to the law.[4] The practical relevance of this inquiry is unquestionable, as the causal link is a crucial component of every tort case.[5]

First, I will show that natural scientists and philosophers have long abandoned a strictly deterministic view of the world.[6] Quantum mechanics and chaos theory have demonstrated that perfect predictability is nothing more than a chimera, thus forcing scientists to acknowledge our limits.[7] Bold statements *a la* Laplace[8] have been replaced by a quasi-mystic deference towards the mysteries of nature.[9] In this vein, philosophers of science have accepted chance as a radical ultimate, or at the very least, as unavoidable at an epistemological level.[10] Although some influential legal scholars have acknowledged this indeterministic drift, they generally regarded it as irrelevant to the study of the law.[11] Paradoxically and unwittingly, law and economics scholars have clung to an outdated and non-probabilistic view of the world.[12]

To the contrary, I will argue that legal scholars cannot overlook the

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also WILLIAM L. PROSSER, LAW OF TORTS 237 (4th ed. 1971) (stating that causation in fact, "[o]f all of the questions involved[] . . . is [the] easiest to dispose of that which has been regarded, traditionally, as the most difficult").

[3] FREDERICK POLLOCK, THE LAW OF TORTS: A TREATISE ON THE PRINCIPLES OF OBLIGATIONS ARISING FROM CIVIL WRONGS IN THE COMMON LAW 33 (4th ed. 1895) ("The lawyer cannot afford to adventure himself with philosophers in the logical and metaphysical controversies that beset the idea of cause.").

[4] *See* Steve C. Gold, *When Certainty Dissolves into Probability: A Legal Vision of Toxic Causation for the Post-Genomic Era*, 70 WASH. & LEE L. REV. 237, 239 (2013) ("Courts turn to science to replace causal intuition, but a disjunction remains between the probabilities that science can know and the determined result that the law wants proven."). *See generally* Jamie A Grodsky, *Genomics and Toxic Torts: Dismantling the Risk-Injury Divide*, 59 STAN. L. REV. 1671 (2007); David Rosenberg, *The Casual Connection in Mass Exposure Cases: A "Public Law" Vision of the Tort System*, 97 HARV. L. REV. 851 (1984); Andrew W. Hayes, *An Introduction to Chaos and Law*, 60 UMKC L. REV. 751 (1992).

[5] *See, e.g.*, Kenneth S. Abraham, *Self-Proving Causation*, 99 VA. L. REV 1811, 1811–12 (2013) ("Any negligence case consists of four different elements--duty, breach of duty, damages, and a causal connection between breach of duty and damages.").

[6] *See* discussion *infra* Sections II.B, II.C.

[7] *See, e.g.*, CAPRA, *supra* note 1, at 68 (admitting that "[w]e can never predict an atomic event with certainty").

[8] *See generally* PIERRE SIMON, MARQUIS DE LAPLACE, A PHILOSOPHICAL ESSAY ON PROBABILITIES (Frederick Wilson Truscott & Frederick Lincoln Emory trans., Dover Publications, Inc. 1951) (1812).

[9] The work from Capra is a notable example of this tendency. *See* CAPRA, *supra* note 1, at 68.

[10] *See, e.g.*, MARIO BUNGE, CAUSALITY: THE PLACE OF THE CAUSAL PRINCIPLE IN MODERN SCIENCE 13 (1959); *see also* Mark A. Stone, *Chaos, Prediction and Laplacean Determinism*, 26 AM. PHIL. Q. 123, 123 (1989).

[11] *See* Richard W. Wright, *Causation, Responsibility, Risk, Probability, Naked Statistics, and Proof: Pruning the Bramble Bush by Clarifying the Concepts*, 73 IOWA L. REV. 1001, 1029 n.145 (1988) ("While [scientific uncertainties] might cause problems in hypothetical lawsuits between subatomic particles, it creates no problems in actual tort litigation."). In other words, the problem of non-strictly deterministic (or probabilistic) causation would not be relevant for tort litigation as it relates only to a specific subset of phenomena. For a discussion of the role quantam mechanics has in the debate on causation, see discussion *infra* Sections II.B, II.C.

[12] For a notable example that will be discussed in Part IV, see Steven Shavell, *Uncertainty over Causation and the Determination of Civil Liability*, 28 J.L. & ECON 587 (1985).

findings of natural scientists and philosophers. In fact, the definition of the basic concepts of tort law (i.e., causation and harm) is strictly dependent on the accepted postulates on the nature of the world.[13] Admitting the inherent limits of scientific knowledge forces us to redefine what should be considered the main asset of the victim; in a probabilistic world, a statement of the kind, "I have been harmed because the injurer has been negligent" is incorrect. The only possible statements are in the following form: "Because the injurer has been negligent, I had a greater chance of getting harmed." Saying that the probability of event *A* is zero, equates to saying that the probability of the event non-*A* is equal to one. However, in a probabilistic world, non-*A* cannot be associated to a probability of one as the probability of *A* must be strictly larger than zero for any possible event. Therefore, as even the most remote risk has a positive probability of materializing,[14] a victim simply cannot be entitled to not being harmed. This is a fundamental departure from the traditional and still prevailing approach.[15]

To put it differently, by definition, in a probabilistic world, no event can materialize with a probability equal to one. The other side of the coin is that no event has a probability equal to zero of taking place. It follows that a victim cannot merely be entitled to compensation simply by being at the receiving end of conduct, which consequentially increases the probability of being harmed. Therefore, the asset of any potential victim is the probability of *not* suffering a specific harm, and the *only* possible form of harm is risk creation.

This journey will therefore lead to conclusions that might threaten the survival of fundamental characteristics of modern legal systems.[16] In fact, pursuing my line of thought until the very end, bare logic will suggest the need to introduce systematic compensation in absence of any harm in the traditional sense.[17] To temper the normative implications flowing from the analysis presented, I will cling to the limits of scientific knowledge and the need for simplification. More precisely, I suggest that by adopting a specific

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[13] *See* discussion *infra* Section V.B. Given this fact, risk cannot be considered harm because we live in a deterministic world. Stephen R. Perry, *Risk, Harm, and Responsibility, in* PHILOSOPHICAL FOUNDATIONS OF TORT LAW 321, 327 (David G. Owen ed., 1995). Furthermore, physical harm has recently been defined as "the physical impairment of the human body . . . . The physical impairment of the human body includes physical illness, disease, and death." RESTATEMENT (THIRD) OF TORTS: LIABILITY FOR PHYSICAL HARM § 4 (AM. LAW INST., Tentative Draft No. 1, 2001).

[14] *See* discussion *infra* Sections V.A, V.B.

[15] *See* Abraham, *supra* note 5, at 1816 n.9 (without supporting its use, Abraham notes that tort law has not replaced the general notion of the "but for" test).

[16] *See* discussion *infra* Sections IV.D, V.A.

[17] More precisely, I will advocate the need to identify risk as *the* source of compensable harm. *See* discussion *infra* Section V.B. There is an extensive debate in the literature on whether risk should be considered compensable harm. *See generally* Gregory L. Ash, Comment, *Toxic Torts and Latent Diseases: The Case for an Increased Risk Cause of Action*, 38 KAN. L. REV. 1087 (1990); Andrew R. Klein, *A Model for Enhanced Risk Recovery in Tort*, 56 WASH. & LEE L. REV. 1173 (1999); Deirdre A. McDonnell, Comment, *Increased Risk of Disease Damages: Proportional Recovery as an Alternative to the All or Nothing System Exemplified by Asbestos Cases*, 24 B.C. ENVTL. AFF. L. REV. 623 (1997).

kind of probabilistic approach to causation, it is possible to offer a reasonable answer to the riddles posed by modern torts without complicating the solution of prima facie deterministic cases.[18]

This Article proceeds as follows. Part II offers a brief overview of how the idea of causation has evolved over the past centuries. In Part III, the concept of causation in the law is briefly sketched. In Part IV, the notion of probabilistic causation is introduced. In Part V, a normative framework is proposed for the treatment of causation in the law of torts. Part VI briefly summarizes the main findings of the Article.

II. THE CONCEPT OF CAUSATION: THE RISE AND FALL OF THE DEMON

The idea of causation has always been inextricably tied to the state of development of natural sciences; thus, it is not surprising that it has dramatically changed over the centuries.[19] Although a comprehensive account of the concept of causation throughout human history lies way outside the scope of this Article, it is necessary to analyze the fundamental shift that took place from Laplacean determinism to modern conceptions of the universe.

A. Determinism and Science: Laplace's Demon

Any philosophical inquiry should start with a clear definition of the terminology. From this perspective, a wide array of definitions of determinism has been advanced, and some of them are, to a certain extent, compatible with the findings of modern science.[20] For the purpose of this Article, the focus can be narrowed down to two kinds of determinism: Laplacean determinism and metaphysical determinism. Both concepts will be introduced in this Section. An important *caveat* is that, depending on the definition adopted, determinism might not imply perfect predictability.[21] However, for the two kinds of determinism considered in this Article, this does not constitute a problem. In fact, Laplacean determinism postulates perfect predictability, whereas for metaphysical determinism, our predictive

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[18] I label as "traditional cases" all those circumstances in which the causal link can be identified in a (apparently) deterministic way (e.g., a pedestrian that has a broken leg after being hit by a car). All the other cases are denoted as modern torts and include medical malpractice, toxic cases, etc.

[19] For an overview of the historical developments of the concept of causation, see BUNGE, *supra* note 10, at 31–52.

[20] *See* John Earman, *Aspects of Determinism in Modern Physics*, *in* 2 HANDBOOK OF THE PHILOSOPHY OF SCIENCE: PHILOSOPHY OF PHYSICS 1373 (John Earman & Jeremy Butterfield eds., 2006) ("There is a tendency in the philosophical literature to fixate on the Laplacian variety of determinism. But other kinds of determinism crop up in physics.").

[21] *See id.* at 1389 ("[P]hilosophers and physicists alike conflate determinism and predictability. The conflation leads them to reason as follows: here is a case where predictability fails; thus, here is a case where determinism fails. This is a mistake that derives from a failure to distinguish determinism — an ontological doctrine about how the world evolves — from predictability — an epistemic doctrine about what can [be] inferred, by various restricted means, about the future (or past) state of the world from a knowledge of its present state.").

capacity is irrelevant.[22]

The manifesto of Laplacean determinism is found in Laplace's treatise on probability:

> We ought to regard the present state of the universe as the effect of its antecedent state and as the cause of the state that is to follow. An intelligence knowing all the forces acting in nature at a given instant, as well as the momentary positions of all things in the universe, would be able to comprehend in one single formula the motions of the largest bodies as well as of the lightest atoms in the world, provided that its intellect were sufficiently powerful to subject all data to analysis; to it nothing would be uncertain, the future as well as the past would be present to its eyes.[23]

To use a less fascinating yet more formal language, the metaphysical determinism implies that:

> A system is said to be "deterministic" when, giving certain data, $e_1, e_2, \ldots, e_n$, at times $t_1, t_2, \ldots, t_n$ respectively, concerning this system, if E_t is the state of the system at any time t, there is a functional relation of the form
>
> $$E_t = f(e_1, t_1, t_2, \ldots e_n, t_n, t). \qquad \text{(A)}$$
>
> The system will be "deterministic throughout the given period" if t, in the above formula, may be any time within that period . . . ."[24]

In other words, in a deterministic universe, the future states are uniquely determined by the preceding ones and by the laws of nature.[25] It is important to note that Laplace's statement affirms more than a metaphysical determinism; it also entails the scientific determinism *a la* Popper.[26] More precisely, the philosopher defines scientific determinism as: "[T]he doctrine that the structure of the world is such that *any event can be rationally predicted, with any desired degree of precision, if we are given a sufficiently*

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[22] *See* KARL R. POPPER, THE OPEN UNIVERSE: AN ARGUMENT FOR INDETERMINISM 6–8 (1988) ("Thus the fundamental idea underlying 'scientific' determinism is that the structure of the world is such that every future event can in principle be rationally calculated in advance, . . ." and "[t]he metaphysical doctrine of determinism simply asserts that all events in this world are fixed, or unalterable, or predetermined. It does not assert that they are known to anybody, or predictable by scientific means.").

[23] ERNEST NAGEL, THE STRUCTURE OF SCIENCE 281 (1961) (quoting LAPLACE, *supra* note 8).

[24] Bertrand Russell, *On the Notion of Cause, with Applications to the Free-Will Problem*, *in* READINGS IN THE PHILOSOPHY OF SCIENCE 398 (Herbert Feigl & May Brodbeck eds., 1953) (noting this definition threatens to strip determinism of all its potential informational content).

[25] *See id.*

[26] *See* POPPER, *supra* note 22, at 1–2; *see also* Earman, *supra* note 20 (analyzing the differences between predictability and determinism).

precise description of past events, together with all the laws of nature."[27]

The main difference between scientific determinism and metaphysical determinism is, therefore, that the former implies the possibility to predict future states of the world, whereas the latter is agnostic on the point.[28]

Notably, metaphysical determinism cannot be proven or disproven, and hence its embracement constitutes a mere act of faith.[29] Nevertheless, because scientific determinism implies metaphysical determinism, any proof in favor of the former can strengthen our faith in the latter.

The extreme confidence in the capacity of human beings to comprehend and uncover the mysteries of nature should not be surprising; Laplace was writing in an age dominated by the deterministic triumph of Newtonian physics.[30] The idea of univocally determined causal links was completely pervasive in every field of human knowledge.[31] No matter how unattractive its extreme consequences were, hardly anyone would have questioned that scientific discoveries were leading us to a complete comprehension of the universe.[32]

The works of Immanuel Kant are the best example of how hard it was to depart from this sacred conception.[33] The German philosopher understood perfectly well the consequences of embracing the form of determinism generally associated with Newtonian physics; in fact, he affirmed that by disposing of complete information, "we could calculate a human being's conduct for the future with certainty, just like any lunar or solar eclipse . . . ."[34]

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[27] *See* POPPER, *supra* note 22, at 1–2.

[28] *See* NAGEL, *supra* note 23, at 281–82.

[29] HANS REICHENBACH, PHILOSOPHIC FOUNDATIONS OF QUANTUM MECHANICS 2 (1944) ("This discrepancy [between idealized and actual physical states] has often been disregarded as irrelevant, as being due to the imperfection of the experimenter and therefore negligible in a statement about causality as a property of nature. With such an attitude, however, the way to a solution of the problem of causality is barred. Statements about the physical world have meaning only so far as they are connected with verifiable results . . . .").

[30] *See generally* JOHN EARMAN, A PRIMER ON DETERMINISM (1986) (providing a thorough discussion on the alleged deterministic nature of Newtonian physics). The deterministic character of Newtonian physics is questionable to say the least. Without taking a side in this extremely complex debate, we will borrow Popper's terminology and define it as "Prima Facie Deterministic." POPPER, *supra* note 22.

[31] POPPER, *supra* note 22, at 7. According to Popper, "The power of the belief in 'scientific' determinism may be gauged by the fact that Kant, who for moral reasons rejected determinism, nevertheless felt compelled to accept it as an undeniable fact, established by science." *Id.*

[32] Henri Poincaré, *Chance*, *in* 22 THE MONIST 31, 31 (G.B. Halsted trans., Kraus Reprint Corp. 1966) (1912) ("We have become absolute determinists, and even those who want to reserve the rights of human free will let determinism reign undividedly in the inorganic world at least. Every phenomenon, however minute, has a cause; and a mind infinitely powerful, infinitely well-informed about the laws of nature, could have foreseen it from the beginning of the centuries. If such a mind existed, we could not play with it at any game of chance, we should always lose.").

[33] *See* POPPER, *supra* note 22, at 7.

[34] IMMANUEL KANT, CRITIQUE OF PRACTICAL REASON 126 (Werner S. Pluhar trans., Hackett Publ'g Co. 2002) (1788).

Kant's devotion to the deterministic nature of Newtonian physics was as strong as his faith in the free will of human beings, and hence, all his philosophy was dominated by the paradox of *noumena*: beings who were free in themselves, yet relegated to live in a predetermined environment.[35] The free will was not powerful enough to free Kant from the demon's chains. Both forms of determinism were postulated to be true.[36]

B. Quantum Mechanics, Chaos Theory, and Predictability

Besides its incredible predictive power, quantum mechanics presents two fundamental characteristics.[37] In the first place, during its initial developments, and in spite of the astonishing experimental successes obtained, no one had a logical explanation for what was happening.[38] Second, in previous centuries, scientific discoveries had been perceived as a step towards the complete comprehension of our universe.[39] Each of these steps increased the confidence of scientists and reinforced the perception that ultimate knowledge was becoming closer and closer.[40] Quantum mechanics abruptly ended these tendencies; the more discoveries that were made, the more paradoxes that emerged, and the more the universe looked too complicated to be fully comprehended.[41] Reichenbach captured these two traits in his treatise: "It was with the phase of the physical interpretations that the novelty of the logical form of quantum mechanics was realized. Something had been achieved in this new theory which was contrary to traditional concepts of knowledge and reality. It was not easy, however, to *say* what had happened . . . ."[42]

The maze unveiled by the Copenhagen School revealed a reality that had very little in common with the typical portrait painted by the scientists and the philosophers of the previous centuries.[43] "Quantum theory has . . .

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35 *See* POPPER, *supra* note 22, at 7.

36 *See id.*

37 Quantum mechanics is the branch of physics that aims at describing the subatomic world. Despite the theoretical riddles, it predicts extremely well the behavior of its object of study.

38 *See* REICHENBACH, *supra* note 29, at v–vi ("It is a most astonishing fact that this phase, which led up to quantum mechanics, began without a clear insight into what was actually being done. . . . This period represents an amazing triumph of mathematical technique which, masterly applied and guided by a physical instinct more than by logical principles, determined the path to the discovery of a theory which was able to embrace all observable data.").

39 *See, e.g.*, CAPRA, *supra* note 1, at 22 ("The fundamental laws of nature searched for by the scientists were thus seen as the laws of God, invariable and eternal, to which the world was subjected.").

40 This is clearly an oversimplification; however, it captures the change in the prevailing approach exemplified by the words of Laplace and the works of Fritjof Capra.

41 *See id.* at 66 ("Every time the physicists asked nature a question in an atomic experiment, nature answered with a paradox, and the more they tried to clarify the situation, the sharper the paradoxes became. It took them a long time to accept the fact that these paradoxes belong to the intrinsic structure of atomic physics . . . .").

42 REICHENBACH, *supra* note 29, at vi.

43 *E.g.*, CAPRA, *supra* note 1, at 17 ("The concept of matter in subatomic physics, for example, is totally different from the traditional idea of a material substance in classical physics. The same is true for concepts like space, time, or cause and effect.").

demolished the classical concepts of . . . strictly deterministic laws of nature."[44]

The main problem is that, within quantum mechanics, it is impossible to predict with absolute certainty the behavior of a single particle.[45] Regardless of the sophistication of the tools used to explore reality, "[w]e can never predict an atomic event with certainty; we can only say how likely it is to happen."[46] To the contrary, statistical predictions on sufficiently large numbers of particles reach peaks of precision and accuracy that are alien to most fields of science.[47] From this perspective, Heisenberg laid one of the building blocks.[48] Roughly speaking, the indeterminacy principle (for position and momentum)[49] that carries his name denies the possibility to identify the exact simultaneous values of position and momentum of a particle.[50] In other words, it is not possible to simultaneously have precise information about the position and the momentum of a particle.[51] This is in sharp contrast with the Laplacean idea of determinism.[52]

There is one widespread misconception about the indeterminacy of observation within quantum mechanics.[53] In fact, it is generally assumed that the reason behind the need to adopt statistical predictions is exclusively the unavoidable interaction between the observer and the observed object.[54] Therefore, the inevitable disturbance of infinitesimally small objects by the means of observation would be the cause of the indeterminacy principle. The obvious corollary to this thesis is that such uncertainty is "washed off" if macroscopic objects are studied. Although the entire argument against this claim cannot be reproduced here,[55] suffice it to say that also within the realm of classic physics, the observational tool alters the observed object, yet not

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44 *Id.* at 68.

45 *Id.*

46 *Id.*

47 *See, e.g.*, Olimpia Lombardi & Martín Labarca, *The Philosophy of Chemistry as a New Resource for Chemistry Education*, 84 J. CHEMICAL EDUC. 187, 187 (2007) (noting that, by no coincidence, some branches of human knowledge are being reinterpreted through the lens of quantum mechanics). "[T]he impressive predictive power of quantum mechanics led most chemists, physicists, and philosophers of science to consider that chemistry can be completely reduced to physics." *Id.*

48 CAPRA, *supra* note 1, at 158.

49 The momentum is the product of the mass and velocity of a particle. For a precise formulation of the indeterminacy principle, see JOHN VON NEUMANN, MATHEMATICAL FOUNDATIONS OF QUANTUM MECHANICS (Robert T. Beyer trans., 1955).

50 *See* CAPRA, *supra* note 1, at 158 ("The better we know the position, the hazier will its momentum be and vice versa. We can decide to undertake a precise measurement of either of the two quantities; but then we will have to remain completely ignorant about the other one. It is important to realize[] . . . that this limitation is not caused by the imperfection of our measuring techniques, but is a limitation of principle.").

51 *Id.*

52 *See supra* notes 23–29 and accompanying text.

53 *See* REICHENBACH, *supra* note 29, at 16 (expressing that Heisenberg himself embraced this misconceived perspective).

54 *Id.*

55 For a mathematical proof that the disturbance of the observational means is not the cause of the degree of uncertainty in the predictions, see *id.* at 17 n.1, 104.

necessarily in an unpredictable way.[56] In fact, the observational means are not different in nature from any other physical entity that interacts with the observed object, and hence, if the observational means influence on the observed object is unpredictable, so could be that of any other entity.[57] It follows that the influence of the means of observation in itself cannot explain the indeterminacy of predictions.[58] Only when combined with the indeterminacy principle does it become a sufficient condition.[59]

From the considerations developed above, it follows that quantum mechanics cannot be reduced to a strictly deterministic theory, nor can its philosophical implications be relegated at the microscopic level.[60] Although quantum mechanics do not rule out every deterministic explanation of the world,[61] a first mortal wound was inflicted on the demon. In fact, quantum mechanics *is* incompatible with Laplacean determinism. Incidentally, I will show that this is the kind of determinism postulated by many influential legal, as well as law and economics scholars.

C. Chaotic Systems and Predictions

The seeds of a second ambush on the demon were planted by James Clerk Maxwell and Henri Poincaré. Laplace's determinism is in fact grounded on two hidden assumptions.[62] In the first instance, Laplace's hypothesis requires that small causes produce small effects; in other words, small imperfections in the initial data generate only small deviations in the

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[56] *See id.* at 16–17 (using the words of Reichenbach, "Instruments of measurement do not represent exceptions to physical laws[] . . . . [Thus,] [w]hen we put a thermometer into a glass of water we know that the temperature of the water will be changed by the introduction of the thermometer; therefore we cannot interpret the reading taken from the thermometer as giving the water temperature before the measurement, but must consider this reading as an observation from which we can determine the original temperature of the water only by means of inferences. These inferences can be made when we include in them a theory of the thermometer").

[57] *Id.* at 16.

[58] *See id.* ("To say that the indeterminacy of predictions originates from the disturbance by the instruments of observation means that whenever there is a non-negligible disturbance by observation there will always be a limitation of predictability. A consideration of classical physics shows that this is not true. There are many cases in classical physics where the influence of the instrument of measurement cannot be neglected, and where, nevertheless, exact predictions are possible.").

[59] *Id.* at 17.

[60] The most famous description of quantum uncertainty affecting a macro-observable phenomenon is the Schrödinger's Cat problem. To oversimplify, Schrödinger describes a scenario in which a cat is both dead and alive (more precisely it should be said that the cat is in a superposition of two states—dead cat and alive). *See* Hilary Putnam, *A Philosopher Looks at Quantum Mechanics (Again)*, 56 BRIT. J. PHIL. SCI. 615, 620–21 (2005).

[61] *See* TOBY HANDFIELD, A PHILOSOPHICAL GUIDE TO CHANCE 146 (2012).

[62] *See* W. J. Firth, *Chaos—Predicting the Unpredictable*, 303 BRIT. MED. J. 1565, 1565 (1991).

results.[63] However, as both Poincaré[64] and Maxwell[65] noticed, this is not an absolute truth, and in fact it generally holds only for linear systems, while nature is pervaded by chaotic systems.[66] In chaotic systems, small differences in initial conditions cascade through various iterations into drastically different outcomes.[67] As to the second assumption, Laplace assumes an increase in the calculation power of roughly the same proportion in order to increase the number of objects studied.[68] Once again, this relationship is not linear, as it was imagined by the French mathematician; therefore, the increase in calculation power required to analyze complex systems grows at a very fast rate, making it very hard to imagine that complex systems can be captured in their entirety.[69] Given that chaotic systems are extremely sensitive to infinitesimal variations of initial conditions, it is clear why chaos theory poses an insurmountable obstacle to our capacity to make predictions. On the one hand, in any field of human knowledge, we can define the initial conditions only with a certain degree of precision, and on the other, we can only include a limited number of factors in our analysis. In the words of

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[63] *Id.*

[64] Poincaré, *supra* note 32, at 34 (In a very famous passage, Poincaré stated: "A very slight cause, which escapes us, determines a considerable effect which we cannot help seeing, and then we say this effect is due to chance. If we could know exactly the laws of nature and the situation of the universe at the initial instant, we should be able to predict exactly the situation of this same universe at a subsequent instant. But even then when the natural laws should have no further secret for us, we could know the initial situation only *approximately*. If that permits us to foresee the subsequent situation *with the same degree of approximation*, this is all we require, we say the phenomenon has been predicted, that it is ruled by laws; but it is not always so. It may happen that slight differences in the initial conditions produce very great differences in the final phenomena; a slight error in the former would make an enormous error in the latter. Prediction becomes impossible and we have the fortuitous phenomenon").

[65] LEWIS CAMPBELL & WILLIAM GARNETT, THE LIFE OF JAMES CLERK MAXWELL 440 (1882) (affirming, in a lecture Maxwell delivered at Cambridge in 1873: "Much light may be thrown on some of these questions by the consideration of stability and instability. When the state of things is such that an infinitely small variation of the present state will alter only by an infinitely small quantity the state at some future time, the condition of the system, whether at rest or in motion, is said to be stable; but when an infinitely small variation in the present state may bring about a finite difference in the state of the system in a finite time, the condition of the system is said to be unstable. It is manifest that the existence of unstable conditions renders impossible the prediction of future events, if our knowledge of the present state is only approximate, and not accurate. It has been well pointed out by Professor Balfour Stewart that physical stability is the characteristic of those systems from the contemplation of which determinists draw their arguments, and physical stability that of those living bodies, and moral instability that of those living bodies, and moral instability that of those developable souls, which furnish to consciousness the conviction of free will").

[66] Firth, *supra* note 62, at 1565 ("[C]haos[] . . . has shown us that predictability is the exception rather than the rule, even for what seem like simple physical systems.").

[67] To have a flavor of the dramatic variance in the results it suffices to recall how nonlinear theory attracted the attention of the scientific community. Higgins writes that,

In 1961, Edward Lorenz, a mathematician-meteorologist working at the Massachusetts Institute of Technology, observed what he believed was order masquerading as randomness. He used a simple mathematical model of weather patterns and a computer capable of performing multiple iterations (repetitions). After accidentally inputting an incorrect decimal point in a number, he noted that small variations in initial conditions (temperature or atmospheric pressure) would cascade through various iterations into remarkably different output (weather conditions).

John P. Higgins, *Nonlinear Systems in Medicine*, 75 YALE J. BIOLOGY & MED. 247, 249 (2002).

[68] Firth, *supra* note 62, at 1565.

[69] *Id.*

Poincaré, "[p]rediction becomes impossible . . . ."[70]

The paradox of isolation offers a nice perspective of the desperate battle that the demon is fighting;[71] to understand causes and effects, it is necessary to isolate the components that are being studied. The more we can isolate the components that we want to study, the more precisely we can analyze initial conditions.[72] Clearly, to obtain absolute precision in the definition of initial conditions, we need to completely isolate the component that we want to study.[73] Yet, if we assume that it is possible to completely isolate a specific component, the doctrine of universal causal interdependence is defeated.[74] In other words, chaos theory proves that to achieve Laplacean predictability, we need to be able to define initial conditions with an infinite degree of precision, but the more we do so, the more we undermine metaphysical determinism.[75] Complete Laplacean determinism requires the death of metaphysical determinism, yet metaphysical determinism is a necessary condition for Laplacean determinism, so that nothing can be predicted in the way imagined by the French mathematician. Not coincidentally, Reichl writes, "we now know that the assumption that Newton's equations can predict the future is a fallacy";[76] not even the most deterministic of all theories meets the standard defined by Laplace and by legal scholars.

During the past decades, it has been discovered that chaotic systems are ubiquitous in nature;[77] therefore it became evident that the demon was finally defeated. Scientific determinism had to be abandoned, and hence, our faith in metaphysical determinism ought to be weakened.

III. DEMONS FROM THE PAST: CAUSATION IN THE LAW

In limiting oneself to a single jurisdiction, a whole article would not suffice to offer an even remotely accurate account of the countless facets of causation in the law. In this very brief overview, I will follow the non-conventional approach of Professor Guido Calabresi and "distinguish three concepts of 'cause': 'causal link,' '*but for* cause,' and 'proximate cause.'"[78]

The "causal link" is the closest relative to the idea of causation studied in natural sciences and in philosophy. The focus is on empirical

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[70] *See* Poincaré, *supra* note 32, at 34.
[71] *See* BUNGE, *supra* note 10, at 129–32.
[72] *Id.* at 129.
[73] *Id.*
[74] *Id.*
[75] *Id.* at 129–32.
[76] LINDA E. REICHL, THE TRANSITION TO CHAOS: CONSERVATIVE CLASSICAL SYSTEMS AND QUANTUM MANIFESTATIONS 3 (2d ed. 2004).
[77] Firth, *supra* note 62, at 1565.
[78] Guido Calabresi, *Concerning Cause and the Law of Torts: An Essay for Harry Kalven, Jr.*, 43 U. CHI. L. REV. 69, 71 (1976).

patterns and on the idea that a certain factor will increase the likelihood of a certain (negative) outcome.[79] It must be noted, however, that, technically speaking, there is an infinite spectrum of factors that is causally linked to every injury.[80] Therefore, the causal inquiry within the law has to be limited to the connection between actions under the control of human will and the harm suffered by the victims.[81]

The second concept is the "*but for* cause." From this perspective, causation is established if the damage would have not occurred *but for* the breach of duty. As traditionally conceived by legal scholars, the *but for* test was considered to be strictly deterministic; however, it can be adapted to a probabilistic view of the world.[82] The difference between the two interpretations of the test would then lie in how often the "*but for* cause," *C*, is assumed to be followed by the effect, *E*. If E invariably follows *C*, then the *but for* test has a deterministic nature. Conversely, the *but for* test has a probabilistic form when stated in the following terms: "the probability of *E* occurring *but for C* would have been lower." In this case, the probability of *E* following *C* is never exactly equal to zero and one.

An interesting evolution of this approach was introduced by Professors Hart and Honoré,[83] and was developed by Professor Richard Wright.[84] The "Necessary Element of a Sufficient Set" ("NESS") test that they propose is built on the idea that: "[*A*] *particular condition was a cause of (contributed to) a specific result if and only if it was a necessary element of a set of antecedent actual conditions that was sufficient for the occurrence of the result*."[85]

Lastly, the elusive concept of "proximate cause" prevents the defendants from being held liable for the additional harm caused by an intervening event that breaks the chain of causation between the negligent act and the harm.[86] Many (often contradictory) justifications have been presented

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[79] *See id.*
[80] *Id.*
[81] It should, however, be noted that determining which actions are within human control is an incredibly difficult—if not impossible—task. *See* MICHAEL S. MOORE, CAUSATION AND RESPONSIBILITY: AN ESSAY IN LAW, MORALS, AND METAPHYSICS 20–33 (2009); *see also* Giuseppe Maggio, Alessandro Romano & Angela Troisi, *The Legal Origin of Income Inequality*, 7 L. DEV. REV. 1, 15–18 (2014) (arguing that it is practically impossible to distinguish between factors within and outside human control).
[82] *See, e.g.*, Robert Cooter, *Torts as the Union of Liberty and Efficiency: An Essay on Causation*, 63 CHI.-KENT L. REV. 523, 526 (1987) (describing the tension between the deterministic version of the *but for* test and a more probabilistic view of causation).
[83] *See* H. L. A. HART & TONY HONORÉ, CAUSATION IN THE LAW 109–14 (2d ed. 1985).
[84] *See* Wright, *supra* note 11, at 1019.
[85] *Id.*
[86] There is no consensus on the definition of proximate cause. *See Proximate Cause*, BLACK'S LAW DICTIONARY (10th ed. 2014); *see also* W. PAGE KEETON ET AL., PROSSER AND KEETON ON THE LAW OF TORTS 263 (Lawyer's ed., 5th ed. 1984) ("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.").

to explain the emergence of proximate cause in the common law realm.[87] An especially relevant justification is the concern for limiting the compensation owed by the injurer to the foreseeable consequences of his negligent conduct.[88]

It is not hard to prove that among legal scholars a deterministic view of the universe is still prevailing. An influential writer like Professor Wright, no earlier than 2011, affirmed that:

> [C]ausal law is a law of nature; it describes an empirically based, invariable, ***nonprobabilistic*** relation between some minimal set of abstractly described antecedent conditions and some abstractly described consequent condition, such that the concrete instantiation of all the antecedent conditions will always immediately result in the concrete instantiation of the consequent condition. Any concrete condition that is part of the instantiation of the completely instantiated antecedent of the causal law is a cause of (contributed to) the instantiation of the consequent.[89]

The demons of the past are alive in the realm of the law, while modern science is not. Moving from these axioms, it is not surprising that when the law is confronted with the findings of modern science—generally expressed in terms of probabilistic relations—many problems arise.

A. Why Should Legal Scholars Fight the Demon?

In an extremely important article, Jacques Hadamard[90] proves that "no finite degree of precision of initial conditions will allow us to predict whether or not a planetary system (of many bodies) will be stable in Laplace's sense."[91] The problem, however, is that the initial conditions can never be defined with infinite precision (neither can be captured with infinite precision

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[87] For an extensive discussion on the point, see Patrick J. Kelley, *Proximate Cause in Negligence Law: History, Theory, and the Present Darkness*, 69 WASH. U. L.Q. 49, 49–50 (1991).

[88] One of the pioneers of this idea was Fredrick Pollock, and the concept, as exemplified by Robert Fischman, still has relevance today. *See* FREDERICK POLLOCK, LAW OF TORTS 32 (St. Louis: The F.H Thomas Law Book Co. 1894) ("[F]or the purpose of [establishing] civil liability [in the first instance], those consequences, and those only, are deemed 'immediate,' 'proximate,' or, to anticipate a little, 'natural and probable,' which a person of average competence and knowledge, being in the like case with the person whose conduct is complained of, and having the like opportunities of observation, might be expected to foresee as likely to follow upon such conduct."); *see also* Robert L. Fischman, *The Divides of Environmental Law and the Problem of Harm in the Endangered Species Act*, 83 IND. L.J. 682, 688 (2008) ("Common law proximate cause refers to reasonably anticipated consequences or the lack of intervening forces between the challenged activity and harm. The best argument for applying the proximate cause limit . . . is that it is not fair to hold actors responsible for every effect that could be causally linked to their conduct regardless of how remote, unusual, or unforeseeable the consequence.").

[89] Richard W. Wright, *Proving Causation: Probability versus Belief*, *in* PERSPECTIVES ON CAUSATION 205 (Richard Goldberg ed., 2011) (emphasis added) (internal citation omitted).

[90] *See generally* Jacques Hadamard, *Les Surfaces à Courbures Opposées et Leurs Lignes Géodésiques*, 27 J. DE MATHÉMATIQUES PURES & APPLIQUÉES [J.M.P.A.] 27 (1898) (Fr.).

[91] POPPER, *supra* note 22, at 40 (explaining Hadamard's results).

the resulting state), and hence, probabilistic descriptions of phenomena are here to stay. In this regard, Mario Bunge, one of the most influential philosophers of science of our time, writes that:

> This uncertainty in the initial information . . . spoils the one-to-one correspondence among neatly defined states even if, as in classical physics, the theoretical values are supposed to be sharply defined. . . . [Therefore,] *all* laws, whether causal or not, when framed in observational terms acquire statistical features[,] . . .[92] [and] whether chance is regarded as a radical ultimate . . . or not, statistical determinacy has to be accounted for by every philosophy of modern science; it is no longer possible to state dogmatically that chance is but a name for human ignorance, or to declare the hope that it will ultimately be shown to be reduced to causation.[93]

Notably, these words were written over 50 years before the work of Professor Wright,[94] which shows how slowly ideas flow among the different fields of human knowledge.

The scenario does not change much when looking at a philosopher cited by Professor Wright himself: Ernest Sosa. In fact, in the introduction to a collection of articles on causation, Sosa and Tooley write:

> One of the more significant developments in the philosophy of causation in this century has been the emergence of the idea that causation is not restricted to deterministic processes . . . . One suggestion, advanced by philosophers such as Reichenbach, Good, and Suppes, is that probabilistic notions should play a central role in the analysis of causal concepts.[95]

Nevertheless, law scholars have largely adopted two antithetical perspectives with regards to the debate on causation in the scientific and in the philosophical arena: on the one hand, it has been argued that the traditional *but for* test conforms to philosophers' and scientists' idea of causation,[96] whereas on the other hand, it has been affirmed that causation in the law has little (if anything) to do with philosophical or scientific considerations.[97] As

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[92] BUNGE, *supra* note 10, at 71–72.

[93] *Id.* at 17.

[94] *See generally* Wright, *supra* note 89.

[95] Ernest Sosa & Michael Tooley, *Introduction* to CAUSATION 19 (Ernest Sosa & Michael Tooley eds., Oxford Univ. Press 1993) (1941).

[96] *See* Wright, *supra* note 2, at 1775 ("[T]he act must have been a necessary condition for the occurrence of the injury. The test reflects a deeply rooted belief that a condition cannot be a cause of some event unless it is, in some sense, necessary for the occurrence of the event. This view is shared by lawyers, philosophers, scientists, and the general public.").

[97] *See, e.g.*, Jane Stapleton, *Choosing What We Mean by "Causation" in the Law*, 73 MO. L. REV. 433, 447 (2008) ("Traditionally, lawyers disdained philosophical enquiries [sic] into 'causation' as being too abstract or vague.").

I have shown, the former perspective is, for the most part, false,[98] whereas I will argue that the latter is extremely dangerous. On these premises, and especially on the consideration that the law is interested in identifying causal links in concrete single cases, let us analyze how the traditional versions of the *but for* test, the NESS test, and proximate cause all perform in the light of modern science.

The analysis need not be long; the deterministic version of the *but for* test and the NESS test requires that causes are necessary and sufficient, yet, in a non-Laplacean world, no cause is both necessary and sufficient. In a probabilistic world, a set of causes may or may not produce a specific outcome; however, *one single outcome will never be the necessary result of any set of causes*.[99] The other side of the coin is that *no set of causes is a sufficient condition for any outcome*. The deterministic version of the *but for* test and the NESS test can only survive in a Laplacean universe; in the one where we live, however, they lead to the conclusion that no liability ever exists because no conduct can be a necessary and sufficient condition for any harm.

The elusive concept of "proximate cause" does not fare better. The common wisdom is that the doctrine of proximate causation prevents the defendants from being held liable for events that are "too remote";[100] thus, limiting the compensation owed by the injurer to the foreseeable consequences of his negligent conduct. [101]

Borrowing (part of) the taxonomy developed by Professor Mark Grady, let us consider two faces of foreseeability: "freakish risks"[102] and the paradigm SDK ("scientists didn't know").[103] Included in the category of "freakish risks" are all those unusual and abnormal consequences of a determinate action that are too rare to be foreseen.[104] Interestingly, there is simply no reason to talk about proximate cause in order to exclude these events from the scope of liability. According to the traditional economic analysis of law, compensation is due only when the expected harm (magnitude of the harm times the probability) is higher than precaution

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98 *See supra* notes 41–86 and accompanying text.

99 *See* Wright, *supra* note 2, at 1789 (emphasis added) ("A fully specified causal law or generalization would state an invariable connection between the cause and the consequence: given the actual existence of the fully specified set of antecedent conditions, the consequence *must* follow. In other words, the fully specified set of antecedent conditions is *sufficient* for the occurrence of the consequence."). However, this definition of the term "sufficient" is incompatible with probabilistic causation. *See id.*

100 *Remote Cause,* BLACK'S LAW DICTIONARY, *supra* note 86.

101 *See* Fischman, *supra* note 88, at 688.

102 The term is borrowed from Steven Shavell. *See* Steven Shavell, *An Analysis of Causation and the Scope of Liability in the Law of Torts*, 9 J. LEG. STUD. 463, 490 (1980).

103 Mark F. Grady, *Causation and Foreseeability*, *in* RESEARCH HANDBOOK ON THE ECONOMICS OF TORTS 114, 133 (Jennifer Arlen ed., 2013).

104 *See* Shavell, *supra* note 102, at 490.

costs.[105] By definition, a "freakish risk" will have a very low probability of materializing, and therefore, the expected harm will systematically be much smaller than the harm itself; compensation will generally not be triggered. In other words, the frequency of an event is a factor that should enter the negligence calculus and not the debate on causation.

The SDK paradigm deals with a very different set of cases in which it is not known ex-ante that a certain conduct is dangerous. Take, for example, the *Overseas Tankship (U.K.) Ltd. v. Morts Dock & Engineering Co.* case.[106] Here, the defendant did not prevent the bunker oil of his ship from reaching Sidney Harbor.[107] Given the state of the art of scientific knowledge, this situation was perceived as relatively safe because bunker oil was considered nonflammable when spread on water.[108] However, the bunker oil soon ignited and destroyed the plaintiff's dock.[109] The court decided that no compensation was due because the accident was not foreseeable at the time in which the defendant negligently allowed the bunker oil to escape from its ship.[110] This is despite the fact that ex-post, it became clear that the "untaken precaution" would have been effective (and efficient) in preventing the harm.[111] Professor Grady concludes that "[t]o impose liability in this situation for a possibly efficient act could only reduce activity levels or induce inefficient precaution substitutions."[112]

Let us analyze this problem in a probabilistic context in which scientific knowledge is inherently probabilistic. Let us define t_0 as the time of the accident and t_1 as the time when it becomes known that bunker oil is flammable also when spread on water. In t_0, the injurer thought that there was a probability p_0 of an accident, whereas in t_1, scientific studies suggested that the probability was equal to p_1 (with $p_0 < p_1$). Due to the limits of scientific knowledge, neither p_0 nor p_1 is equal to the real probability (say p^*). However, scientific studies suggested that p_1 was a more accurate approximation of p^*. "Foreseeability" then reduces to the choice between the less or the more accurate approximation of p^* in the negligence finding. Adopting a dynamic perspective, contrary to Professor Grady, this choice involves a trade-off recognized by the law and economics literature.[113] In

105 .*See* United States v. Carroll Towing Co., 159 F.2d 169, 173 (2d Cir. 1947) (advocating the use of a formula for determining whether a person's conduct fell below the appropriate standard of care. Efficiency requires that marginal costs and benefits are considered).
106 *See generally* [1961] 1 AC 388 (HL) (appeal taken from Wales) (UK).
107 *Id.* at 389.
108 *Id.*
109 *Id.*
110 *Id.*
111 Grady, *supra* note 103, at 134.
112 *Id.*
113 This trade-off in the law and economics literature is generally framed in terms of strict liability versus negligence, with the former giving more incentives in discovering new risks. *See, e.g.*, Alfred Endres & Regina Bertram, *The Development of Care Technology under Liability Law*, 26 INT'L REV. L. &

terms of efficiency, by opting for p_0, the court will prevent the effects described by Professor Grady, whereas choosing p_1, the court will incentivize research and development activities. Similarly, if the problem is framed in terms of corrective justice, it might be more or less desirable that unknown risks are borne by the injurer depending on the concept of fairness adopted. It is, however, apparent that this trade-off has nothing to do with causation.

Lastly, the idea that an event might break the chain of causation is problematic. As noted by Stephen J. Morse: "It is metaphysically implausible that there are 'sharp breaks' in the 'causal chains' of the universe that would provide a moral rationale for the same sharp breaks in legal doctrine . . . . [C]ausation just keeps rolling along."[114] In other words, as the concept of proximate cause implies, causal chains, which in turn are fictitious,[115] are detached from the modern debate on causality.[116] Thus, it is not surprising that proximate cause becomes a vehicle to introduce policy goals that are not related to the cause-effect relationship.[117]

Recently, Professor Michael Moore offered an interesting alternative description of the concept of intervening cause.[118] In his view, the strength of legal "[c]ausation diminishes over the number of events through which it is transmitted."[119] This conceptualization of the idea of intervening cause is, however, unworkable in a world (like ours) in which time and space are continuous and not discrete. In a continuous world, no matter how contiguous two events might appear in time and in space, there are always infinite events separating them. Let us assume that it is possible to represent a series of events on a Cartesian Plane where the horizontal axis is the time and each event is a point ("event-point"). If the series of events is represented by a continuous function (i.e., we are not describing a discrete world), there will always be infinite event-points separating any two given event-points. Or, to go back to the issue of proximate causation, there will always be infinite event-points separating the "proximate" cause and the "proximate" effect.

Alternatively, the problem could be framed in the following way. Let

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ECON. 503 (2006). The problem in this context is similar. If firms are shielded from new risks because courts will adopt p_0, they will have less incentive in discovering new sources of risk and new remedies.

114 Stephan J. Morse, *The Moral Metaphysics of Causation and Results*, 88 CAL. L. REV. 879, 880, 889 (2000).

115 *See* BUNGE, *supra* note 10, at 128 ("Just as ideal objects cannot be isolated from their proper context, material existents exhibit multiple interconnections; therefore the universe is not a heap of things but a system of interacting systems. As a consequence, a particular effect E is not only the product of the *vera e primaria causa* C . . . , but of many other factors . . . .").

116 *Id.*

117 Although taking a different path, a similar conclusion was reached by the early U.S. Realists. In their perspective, proximate causation devices were "word magic whereby unprincipled limitation-of-liability decisions could be achieved at will or whim by untrammeled judges." David W. Robertson, *Allocating Authority Among Institutional Decision Makers in Louisiana State-Court Negligence and Strict Liability Cases*, 57 LA. L. REV. 1079, 1114 (1997).

118 Morse, *supra* note 114, at 879.

119 MOORE, *supra* note 81, at 153.

us assume that we want to understand how many event-links separate the proximate cause, *A*, from the proximate effect, *B*. We will define event-link as any event that has an effect on *A* and *B*. As shown by the paradox of isolation described in Section II.C, it is impossible to perfectly isolate some events from the others.[120] To put it differently, there are no absolute boundaries in nature, and hence, every event has some direct or indirect influence on *A* and *B*. Because we live in an infinitely large universe, and because no boundary can be drawn between any event and *A*/*B*, there will always be infinite event-links separating *A* and *B*.

A possible counter-argument would be that most of these events only have a negligible impact on the *A*/*B* relationship. However, this argument adds an additional layer of complexity. First, it presupposes that it is possible to measure the intensity of the connection between any given event-link and *A*/*B*. Second, even accepting this unlikely assumption, this line of thought implies that an arbitrary threshold must be drawn to decide what is the minimum intensity accepted for an event to be considered an event-link. This entirely arbitrary choice, which is not causal in nature, would in turn determine whether the number of event-links is low enough or not. Also, notably, the choice on the number of event-links that renders a cause not proximate is entirely arbitrary and not causal in nature.

In short, unless absolutely arbitrary thresholds are introduced, the number of event-links separating two given events is always infinity. Therefore, if legal causation loses strength when the number of event-links is high then legal causation can never be established.

IV. THE PROBABILISTIC APPROACH TO CAUSALITY

Before developing the argument in support of probabilistic causation, a preliminary remark is required. As the demon of scientific determinism has been defeated by modern science, there is no longer any reason to postulate metaphysical determinism.[121] The pendulum has swung from prima facie scientific knowledge, which suggested the existence of metaphysical determinism, to the presumption that chance is to be considered a radical ultimate. The fact that metaphysical determinism itself has not been falsified should not be perceived as a proof of its strength, but as a sign of its inherently conjectural nature.[122]

The inadequateness of deterministic causation as an approach to

[120] *See, e.g.*, CAPRA, *supra* note 1, at 25 ("The further we penetrate into the submicroscopic world, the more we shall realize how the modern physicist, like the Eastern mystic, has come to see the world as a system of inseparable, interacting and ever-moving components with the [observer] being an integral part of this system.").

[121] *See supra* notes 41–86 and accompanying text.

[122] *See* POPPER, *supra* note 22, at 6–8; *see also* REICHENBACH, *supra* note 29, at 2.

explore the world has violently emerged over the last decades.[123] In considering toxic torts, what has been discussed in the previous Sections is far from being a purely philosophical and abstract whim.[124] Some scholars had hoped that scientific discoveries would have ameliorated (if not solved) the problem of indeterminate causation in this area, yet the reality is drastically different; a "deeper knowledge will extend rather than resolve the causal indeterminacy problem . . . ."[125] In this vein, the scientists operating in the field have no doubt; "the probabilistic description of the mutation process cannot be replaced by a deterministic one,"[126] given the importance of stochastic events.[127]

A. A Pure (ex-ante) Probabilistic Approach

A pure (ex-ante) probabilistic approach to causation is grounded on four building blocks:

1. The main asset of any potential victim is formed by the probability of *not* suffering a specific harm (Pr).
2. Causation is established whenever Pr is affected by the (negligent) conduct of a potential injurer.
3. Compensation is due when—given the level of scientific knowledge—it should be concluded that Pr was reduced by the (negligent) conduct of the tortfeasor.
4. Compensation must be proportional to the Pr lost.

Given its importance, some elaboration is required on the first point. In a probabilistic world, it is impossible to be certain of being immune from a specific kind of harm. Even the most remote risk will always have a positive probability of materializing. A statement of the kind, "I have contracted the disease, *D*, because the firm, *A*, has polluted the environment" is therefore incorrect. The only possible statements are in the following form: "because the firm, *A*, has polluted the environment, I had a greater chance of contracting the disease, *D*." In other words, the victim has never had an entitlement to

[123] In this regard, Robinson writes that "[t]he recent onslaught of 'toxic,' 'catastrophic injury,' or 'mass disaster' tort cases has made heavy demands on the tort system. The litigation is complex, the victims are numerous, the aggregate losses are daunting, and uncertainty over the causal origins of injury creates exceptional problems of proof." Glen O. Robinson, *Probabilistic Causation and Compensation for Tortious Risk*, 14 J. LEG. STUD. 779, 779 (1985).

[124] Steve Gold gave an influential definition of "toxic tort." He wrote that a toxic tort is "an alleged personal injury and related harm resulting from exposure to a toxic substance -- usually a chemical, but perhaps a biological or radiological agent." Steve Gold, Note, *Causation in Toxic Torts: Burdens of Proof, Standards of Persuasion, and Statistical Evidence*, 96 YALE L.J. 376, 376 n.1 (1986).

[125] *See* Gold, *supra* note 4, at 240.

[126] ANATOLY RUVINSKY, GENETICS AND RANDOMNESS 39 (2010).

[127] *See generally* Robin Holliday, *DNA Methylation and Epigenetics Mechanisms*, 15 CELL BIOPHYSICS 15 (1989). The number of articles in which the role of probabilistic considerations is emphasized is enormous and rapidly growing. For an in-depth analysis of the role of probability in toxic cases, see Gold, *supra* note 4.

not contracting the disease, *D*. The victim was merely entitled to not being on the receiving end of negligent conduct that increased the probability of contracting *D*. From these considerations, it follows that the asset of the victim with regards to the disease, *D*, is not his entitlement to being healthy, but the probabilities that he had of not contracting the disease.

One crucial piece of the puzzle is, therefore, that subjecting another person to risk (i.e., reducing his probability of not being harmed) constitutes harm in itself. In this regard, Professor Stephen Perry argues that as far as it is possible to discriminate between the victims that contracted *D* due to *A*'s pollution and those who contracted it due to the background risk, it makes no sense to consider risk compensable harm.[128] Three important implications naturally follow.

First, Professor Perry's argument postulates the existence of the demon and, in fact, he echoes Laplace by affirming that "a distinction can be drawn *in principle* between the two categories of case[s] . . . ."[129] However, chaos theory, quantum mechanics, and the works of Hadamard[130] have shown that perfect predictability cannot be achieved, and therefore, it is not possible to perfectly discriminate among different causes—not in practice and not in principle. Not surprisingly, the arguments used by Professor Perry to rule out the indeterministic hypothesis are extremely weak. On the one hand, he makes an unsubstantiated claim on the allegedly deterministic nature of the causal process analyzed by the House of Lords in the famous case, *Hotson v. East Berkshire Area Health Authority*.[131] On the other hand, he relies on the controversial philosophical thesis that the indeterminism at a macroscopic level is simply washed off.[132] In a world in which scientific determinism does not hold, Professor Perry's arguments lose all of their strength.

Second, it is clear that the thesis advocated in this Article goes beyond merely supporting proportional liability. By exorcising the demons of scientific determinism, the philosophical foundations of a new concept of harm are laid. As recognized by Professor Perry himself, in a probabilistic world, material harm is not the only possible kind of harm.[133] In this vein, the

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[128] Perry, *supra* note 13, at 338.
[129] *Id.* at 334.
[130] *See* discussion *supra* Sections II.B, II.C.
[131] [1987] 1 AC (HL) 3–4 (Eng.). Professor Perry writes that "in many of the fact situations in which risk damage has been alleged, the causal processes at work seem more likely to have been deterministic than indeterministic in character. This is true of *Hotson*, for example, where the House of Lords made the very plausible assumption that at the time the plaintiff arrived at the hospital *either* enough blood vessels were still intact to make his injury treatable, *or* enough had been destroyed to make avascular necrosis inevitable." Perry, *supra* note 13, at 337. There is *nothing*, however, that can induce one to think that the causal process was indeed deterministic. *See id.*
[132] *Id.* On this regard, Putnam writes "there is something special about macro-observables [that] seems tremendously unlikely . . . ." Putnam, *supra* note 60, at 628.
[133] Perry is perfectly aware that his argument holds only in a purely deterministic world. Perry, *supra* note 13, at 337 ("In the indeterministic case there seems to be a true detrimental shift in position that is simply not present in the deterministic case . . . .").

harm can be defined as the reduction of this probability caused by the injurer. The need for this new concept of harm is even more pronounced now that technological progress is turning the traditional concept of physical harm into a "hopelessly imprecise screening device . . . ."[134] In fact, as Professor Jamie Grodsky nicely put it, new technologies are dismantling the risk-injury divide by making it impossible to draw a bright-line distinction between risk and harm.[135]

Third, it is possible to provide an answer to those who claimed that legal scholars should not follow natural sciences in their indeterministic drift.[136] As proven by Professor Perry, the only way to detect the existence of a kind of harm based on ex-ante probabilities is to acknowledge that scientific determinism is a relic of the past.[137] At the same time, clinging to scientific determinism would not make this harm evaporate. It would simply make the law blind to it.

Notably, hidden in a probabilistic approach there is a risk of infinite regress. Once a probabilistic view of the world is embraced *tout court*, it must also be recognized that probabilistic predictions are reliable only with a certain probability.[138] A statement in the form, "Firm *A* has increased the probability of contracting disease *D* by 10%" can only be as reliable as the studies on which it is grounded. If a probabilistic approach is embraced to stay away from the deterministic demon, compensation should be scaled down to account for the finite accuracy of the study. Acting otherwise, the result of the study would be considered absolutely true, and this is in sharp contrast with a probabilistic view of the world. That is to say, if the harm is equal to 10 and the reliability of the study is 90%, then compensation should equal 9 (10 x 0.9). Unfortunately, this is only the tip of the iceberg. Also the reliability of the probabilistic study can be determined only with a certain probability, say, for example, again 90%. To account for this factor, compensation should be lowered to 8.1 (10 x 0.9 x 0.9). As in a probabilistic world, deterministic statements are barred. This chain of probabilistic statements is clearly infinite. In this vein, the original value of compensation has to be multiplied for an infinite number of factors, all strictly smaller than one. It follows that, no matter how large the harm is and how accurate the studies are, the compensation owed by any injurer will always tend to equal zero.

Albeit apparently abstract, this consideration has an immediate

[134] Potter v. Firestone Tire & Rubber Co., 863 P.2d 795, 810 (Cal. 1993).

[135] Not surprisingly, she also notes that "there is no consistency in the courts as to what constitutes physical injury." Grodsky, *supra* note 4, at 1684–85 (discussing this point extensively); *see also* D. Scott Aberson, *A Fifty-state Survey of Medical Monitoring and the Approach the Minnesota Supreme Court Should Take When Confronted with the Issue*, 32 WM. MITCHELL L. REV. 1095, 1115–16 (2006).

[136] *See* Wright, *supra* note 11, at 1029.

[137] Perry, *supra* note 13, at 337.

[138] Assuming the use of confidence intervals in statistics.

practical implication. Most of the literature has generally portrayed all-or-nothing and proportional liability as mutually exclusive alternatives,[139] whereas, in a probabilistic world, they become necessary complements. As probabilistic predictions only have a finite confidence, a probabilistic approach is unworkable without drawing an arbitrary and artificial deterministic line to temper its consequences. In Part V, I will try to establish where this deterministic line should be drawn.

B. A Possible Counterargument

Although probabilistic analysis of causality is gaining momentum among philosophers and has become pervasive in nearly every field of human knowledge, some problems still exists. Given the practical nature of the inquiry and the need for the law to provide answers in states that are extremely far from idealized experiments, I will not systematically discuss each of these criticalities.[140] One point, however, needs to be addressed. The traditional probabilistic approach to causality defines a cause as an event that *increases* the probability that a certain outcome will materialize.[141] As explained by Sosa and Tooley, this definition of probabilistic causation has a fundamental problem.[142] Suppose that two different kinds of disease exist: the first disease, *C*, is fatal with a probability of 0.1, and the second disease, *D*, has a probability of 0.8. Let us also assume that each disease confers immunity against the other. Finally, let us assume that at least half of the people contract *D*.[143] As noted by Sosa and Tooley, "both the unconditional probability of death, and the probability of death given the absence of the first disease, are greater than the probability of death given the presence of the disease, even though, by hypothesis, the disease does cause death with a certain probability."[144]

It seems that for both practical and philosophical reasons, the relevance of this problem might be limited. First, the problem with the example presented above is that it equates death as an effect from any possible cause. It is hard to imagine that any theory on causality adopting this approach will take us far. For example, if we assume that *C* causes a fatal heart attack, whereas *D* causes a deadly loss of blood, the apparent contradiction disappears. In fact, *C* would increase the chances of a heart attack and *D* would increase the probabilities of a deadly loss of blood. If we recognize that causes have infinite facets, but we assume that outcomes are

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[139] *See* Shavell, *supra* note 12, at 588–90.

[140] As an example, it is way outside the scope of this Article to discuss dilemmata as the Einstein-Podolsky-Rosen problem, defined by Reichenbach as a "causal anomaly." For a debate on this problem, *see* Bas C. Van Fraassen, *The Einstein-Podolsky-Rosen Paradox*, *in* 29 SYNTHESE 291, 291 (1974).

[141] *See generally* Patrick Suppes, *Conflicting Intuitions about Causality*, 9 MIDWEST STUD. PHIL. 151 (1984).

[142] Sosa & Tooley, *supra* note 95, at 20.

[143] In this simplified example, no other causes of death exist.

[144] Sosa & Tooley, *supra* note 95, at 20–21.

univocally defined, the emerging contradictions will be due to this asymmetric treatment more than to our definition of cause. Conversely, if we admit that we can never define initial conditions with absolute precision (also because they are characterized by infinite dimensions), we should admit that *outcomes cannot be proven to be absolutely identical*. The apparent paradox is vanished already. Second, given the modest purpose of this Article (the enhancement of probabilistic considerations in the law), the importance of this problem is limited. Therefore, instead of talking about causes, we will say that an event has a *causal effect* whenever it *affects* the probabilities of a given outcome.

To understand the gist of this problem let us reproduce the example described above with a slight modification. In order to make the idealized scenario relevant to tort law, we will assume that *C* and *D* are causally related to the pollution produced by two factories *A* and *B*. All the other assumptions are identical. The pollution from *A* causes disease *C* (fatal 10% of the time), whereas *B* causes disease *D* (that kills 80% of the people who are infected). Once again, each one of these diseases completely immunizes the other.

Four different scenarios are possible, depending on the level of information available:

1. It is not known that the pollution caused by *A* and *B* affects the probability of contracting *C* and *D*. In this case, no liability can be imposed on the two firms.

2. It is known that pollution from one of the firms causes the disease with a certain probability, whereas no information is available with regard to the other firm. In this case, it is unavoidable that the firm who is introducing a known risk will be held liable, while the other will go unpunished.

3. All the relevant information is known, apart from the fact that one disease protects against the other. In other words, it is not known that disease *C* is actually "beneficial." In this case, it is desirable to impose liability on both firms. Liability cannot be excluded on the grounds that pollution from one firm might have a beneficial effect in terms of reducing other dimensions of risk. The reason is simple: this possibility can *never* be ruled out; hence, liability would not be imposed on any conduct.

4. All the information is known. Assuming that there are no policy reasons to shut down firm *D*, then it is socially desirable that firm *C* is not held liable. This is because

> the pollution caused by firm *C* is paradoxically preventing more deaths than it is causing. However, causation *is not the mechanism to achieve this outcome*. In fact, causation is established. *A* affects the probabilities of *C* happening. Yet, *A* should still be shielded from liability due to the positive externalities of its activity.

This result can be achieved either through tort law or by introducing a system of social insurance. In the former case, let us assume that *A* could have prevented the harm by buying a device that fully eliminates its pollution. If positive externalities are introduced in the negligence calculus, *A* will be found negligent only if the cost of the device is lower than the harm it prevents minus the positive externalities. As this difference is negative, no matter how cheap the device is, *A* will never be considered negligent.

Alternatively, a social insurance system would introduce the possibility that the victims of *C* will be compensated by a public fund instead of being compensated by *A*. It should be noted that this solution has already been adopted in many countries for victims of vaccines.[145] Although at first glance this context might appear drastically different, *A* is *de facto* a vaccine against disease *D*. Regardless of the path followed, causation is the wrong tool to protect *A* because the causal link cannot (and should not) be denied. It is a matter of efficient care.

C. The Hidden Demon of Law and Economics

Law and economics scholars have long advocated the use of probabilistic notions in the law, yet, paradoxically in many cases, they did so while relying either implicitly or explicitly on a strictly deterministic view of the world.[146]

Prominent examples of determinism in disguise are found in the works of Professor Steven Shavell on uncertain causation.[147] Early in the set-up of his model, Professor Shavell revealed his Laplacean credo by assuming that "there is one and only one entity for which the following statement is true: 'The accident would not have occurred in the absence of the entity.'"[148] Thus, [w]hen an accident occurs, there will be a chance that the entity that caused it will not be known to the court[,] . . . but the conditional probability

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[145] *See, e.g.*, Lainie Rutkow et al., *Balancing Consumer and Industry Interests in Public Health: The National Vaccine Injury Compensation Program and Its Influence During the Last Two Decades*, 111 PENN ST. L. REV. 681 (2007).

[146] There are some notable exceptions. *See* Calabresi, *supra* note 78, at 71; *see also* Abraham, *supra* note 5, at 1811.

[147] *See* Shavell, *supra* note 12.

[148] *Id.* at 590.

that the entity caused the accident will be determined by the court . . . ."[149] The former statement is typical of Laplacean one-to-one relationships between causes and effects, whereas the latter is a reference to epistemological uncertainty.[150]

Although one might be tempted to question whether these statements are merely working assumptions or a declaration of agnosticism about the nature of the world, the remainder of the article dispels every doubt. Without the need to dig for nuances, Professor Shavell portrays proportional liability and the "all or nothing" approach as mutually exclusive, without recognizing the problem of infinite regress associated with a probabilistic approach.[151] In this vein, Professor Shavell assumes that the probabilistic signal received by the court is perfectly accurate and thus the judge can assess with 100% accuracy the probabilistic contribution of each factor.[152] In his framework, as he overlooks that probabilistic predictions also have a finite level of accuracy,[153] courts are assumed to have perfect information on the causal links taking place in a probabilistic world (even better than quantum physicists). In turn, this rules out every uncertainty surrounding causal investigations.

Therefore, attempting to locate Professor Shavell's work in a probabilistic world produces a paradoxical result. In a probabilistic world, a probabilistic signal is all that there is to know about causal links; as this signal received by the court is assumed to be perfect, Professor Shavell's work on uncertain causation *de facto* rules out the existence of uncertain causation. Predictably, Professor Shavell concludes that the "[u]se of proportional liability results in the same outcome that would be observed in the absence of any uncertainty over causation."[154] Moreover, Professor Shavell writes that "[t]his principle of fairness is in perfect accord with use of a threshold probability criterion in the determination of liability. On the other hand, the principle would be violated by use of proportional liability, as a party would suffer some sanction even when it was unlikely that he caused a harm."[155]

This argument mirrors perfectly with the one advanced by Professor Glen Robinson and by Professors Ariel Porat and Alex Stein; thus, showing that Shavell is not the only influential law and economics scholar to wear this disguise.[156]

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149 *Id.*

150 *See* discussion *supra* Section II.A.

151 *See supra* notes 137–40 and accompanying text.

152 In his model, the court can perfectly observe the conditional probability that an accident caused by the party appears to be of ambiguous origin and the conditional probability that an accident caused by the natural agent appears to be of ambiguous origin. *See* Shavell, *supra* note 12, at 591.

153 *Id.*

154 *Id.* at 599.

155 *Id.* at 605.

156 *See* Robinson, *supra* note 123, at 786; *see also* Ariel Porat & Alex Stein, *Indeterminate Causation and Apportionment of Damages: An Essay on Holtby, Allen, and Fairchild*, 23 OXFORD J. LEG. STUD. 667, 681 (2003).

Following Professor Shavell's assumptions, however, every injurer that could be held liable reduces the victim's chances of not getting harmed. Consequently, according to his own model, there is no risk that liability is imposed on parties who did not cause any harm.[157] His argument on fairness only holds in a world where the following syllogism is true: (i) if there is a binary relationship between causes and effects, and (ii) if such relationship can be identified at least in principle, then (iii) risk creation is not harm in itself. In short, Professor Shavell's argument only holds in a deterministic world, and hence it is possible to offer a univocally deterministic account of the assumptions underlying his model.

D. A Spurious (ex-post) Probabilistic Approach

An alternative way to include probabilistic considerations in the study of causation is by what I will define as a spurious (ex-post) probabilistic approach. This approach is generally referred to as proportional liability,[158] and one of its macroscopic applications was the market share liability imposed on some pharmaceutical firms.[159] This framework is grounded on a deterministic idea of the world, and probabilistic considerations are included only when justified by specific characteristics of the case. Namely, the uncertainty surrounding causal investigations is regarded to be above a certain threshold.[160]

Under this approach, compensation is triggered only in the presence of material harm and the focus is shifted on ex-post probability.[161] The question is framed in the following form: "What is the probability that the accident that has taken place was caused by the alleged injurer?" This is the traditional compromise advocated by law and economics scholars when an idea of probabilistic causation in the law was proposed and has the relevant advantage to allow reaching efficient outcomes, provided that some very restrictive assumptions are verified.[162]

The logic behind this approach can be captured with the following example. Let us assume that a doctor negligently gives a pill with strong side effects to 10 patients and they all die. Let us further assume that this pill is

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[157] *See supra* notes 129–40 and accompanying text. Recall, in fact, that reducing the chances of not getting harmed *is* the only form of harm in a probabilistic world. Claiming that compensation would not perfectly mirror the amount of risk created would not suffice to save Shavell's argument. In fact, under the assumption that risk creation is harm, this problem would be even more severe under an "all or nothing" approach.

[158] *See, e.g.*, John Makdisi, *Proportional Liability: A Comprehensive Rule to Apportion Tort Damages Based on Probability*, 67 N.C. L. REV. 1063, 1064 (1989).

[159] *See* David A. Fisher, *Products Liability—An Analysis of Market Share Liability*, 34 VAND. L. REV. 1623, 1623 (1981) (discussing the theory behind proportional liability and its applications).

[160] *See* Richard Delgado, *Beyond* Sindell*: Relaxation of Cause-In-Fact Rules for Indeterminate Plaintiffs*, 70 CAL. L. REV. 881, 884 (1982); *see also* Sindell v. Abbott Labs., 607 P.2d 924, 937 (Cal. 1980), *cert. denied*, 449 U.S. 912 (1980) (developing a causation theory based on market share).

[161] *See* Shavell, *supra* note 12, at 588.

[162] *Id.* at 589.

responsible for the death of 7 of the patients, but due to epistemological uncertainty it is impossible to identify them. Lastly, let us assume that the value of the life of each of these patients is 100. It follows that the harm caused by the doctor is 700. Optimal deterrence (i.e., compensation equal to expected harm) is achieved if he is ordered to repay each one of the 7 victims with 100. However, this solution is not viable because, by assumption, it is not known who the 7 victims are.

Framed in terms of ex-post probability, the relevant question is: "What is the probability that a given patient has been killed by the pills?" If we assume that patients are identical, the answer is 70% for each patient. In this vein, proponents of this approach argue that optimal deterrence is achieved if the doctor compensates each victim with 70. For this approach to be a viable strategy, the ex-post probability must be known.

V. NORMATIVE IMPLICATIONS

Having defined the two possible approaches to probabilistic causation, the question is how they should be combined to develop a workable and philosophically sound approach to the issue of causation. For the sake of simplicity, I will divide tort cases into two macro-categories: traditional torts and new generation torts. The difference between the two kinds of cases is the prima facie degree of uncertainty surrounding causal investigations. In traditional cases, the causal link can be established prima facie in a deterministic way, whereas causal indeterminacy plagues new generation cases on the very surface.

A. Traditional Torts

Examples of traditional torts are a car hitting a pedestrian or a defective product exploding and hurting a consumer. Events of this kind are generally considered a good reason to embrace a deterministic concept of causation and to postulate the deterministic nature of the world. Both these statements ignore the fact that traditional torts can also be explained by assuming probabilistic relations between causes and effects. To defeat the deterministic argument, it suffices to state that cars hitting pedestrians will cause harm with an extremely high probability. In a more precise language, traditional torts can be coherently interpreted within the probabilistic framework by saying that, given a certain cause, the probability of an event approaches 1. To counter this argument a determinist would have to prove that this causal relationship not only manifests with a probability that is close to 1, but that no exception can ever be found. The impracticability of this quest has been known since Hume.[163]

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[163] William Edward Morris & Charlotte R. Brown, *David Hume*, STAN. ENCYCLOPEDIA OF PHIL., http://plato.stanford.edu/archives/spr2016/entries/hume/ (last modified Dec. 21, 2015).

An important consequence is that whoever argues in favor of a deterministic concept of causation (in the Laplacean sense) will never be able to rule out the probabilistic theory. Furthermore, any deterministic theory runs against the findings of modern science and modern philosophy, which emphasize the importance of probabilistic relations, especially at an epistemological level.[164] Consequently, the only reason to advocate a strictly deterministic concept of causation is an *a priori* belief on the nature of the world. The traditional concept of causation imposes, therefore, such unverifiable dogma on the world.

From a practical perspective, traditional torts are easily handled both by a deterministic and a (ex-post) probabilistic approach to causation. In fact, by assumption, we are dealing with cases where the causal link is established with a probability that departs only infinitesimally from 1. It follows that by adopting a spurious (ex-post) probabilistic approach, compensation would be rounded up to cover for the entire harm.[165] In other words, there is no practical reason to revive the demon when the focus is on traditional torts, as defined here.

B. New Generation Cases

Toxic torts and medical malpractice cases constitute prominent examples of this category of cases. Here, causal indeterminacy haunts every step of causal investigation, and a deterministic fiction is unworkable given the explicitly and intrinsically probabilistic nature of the evidence available to the courts.[166]

1. Ex-ante versus Ex-post Probability

I have defended the idea of a pure probabilistic approach to the study of causation,[167] yet two problems remain open. First, it might be objected that the ex-ante probability of an event is generally extremely hard to measure. This perception stems from the fact that, besides their prima facie deterministic nature, traditional cases also have an additional characteristic trait. For traditional torts, it is generally easier to answer questions regarding the ex-post probability ("what is the probability that the harm suffered by the pedestrian was caused by the careless conduct of the driver that hit him?") than investigating ex-ante probability ("how much the careless driving of the injurer increased the risk of an accident for a certain pedestrian?").[168] In turn,

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[164] *See* BUNGE, *supra* note 10, at 72.

[165] Let us assume that a car hits a pedestrian breaking his or her leg. Let us also assume that the ex-post probability is equal to 99.999999% and that a leg is worth € 100,000. Under the probabilistic approach, the compensation owed would be equal to € 9,999.99. This number will be rounded to € 100,000.

[166] *See* Gold, *supra* note 4, at 319–20.

[167] *See* discussion *supra* Section I.A.

[168] For example, the Third Circuit stated, "[R]ecognizing [monitoring] does not require courts to speculate about the probability of future injury." *In re* Paoli R.R. Yard PCB Litig., 916 F.2d 829, 852 (3d

this has generated a bias in the legal arena as it is automatically assumed that the ex-ante probability of an event is always harder to assess than the ex-post probability.[169]

Unfortunately, asbestos-related claims, the most discussed stream of new generation cases, strengthened this bias.[170] In fact, asbestosis and mesothelioma belong to the category of "signature diseases."[171] The peculiarity of these kinds of cases is that they "nearly always occur[] as a result of exposure to a certain substance."[172] Hence, determining the ex-post probability that a specific substance was the actual cause of the disease is relatively easy, at least in comparison to cases involving non-signature diseases.[173] However, because, for any substance, there is generally more than one source, assigning the ex-post probability to any specific source is not a trivial task. The enormous controversy surrounding causal investigation in asbestos-related litigation testifies that investigating the ex-post probability is problematic even for signature diseases.[174] More importantly, non-signature diseases are rare,[175] so they should be regarded as the exception rather than the norm. In this vein, a theory of causation for new generation cases should not be grounded on cases involving asbestosis, a signature disease, or other non-signature diseases.

Despite this bias, new generation cases often rely on epidemiological studies and do not involve signature diseases.[176] Epidemiological studies explicitly attempt to measure the increase in the risk of a certain outcome associated with a given event (not coincidentally called "risk factor").[177]

Cir. 1990). However, the court was silent in recognizing that by adopting an ex-post perspective, they then needed to speculate about probability. *Id.*

[169] *Id.*

[170] *See generally* STEPHEN J. CARROLL ET AL., ASBESTOS LITIGATION (2005).

[171] *See, e.g.*, Donald G. Gifford, *Calabresi's The Cost of Accidents: A Generation of Impact on Law and Scholarship: The Peculiar Challenges Posed by Latent Diseases Resulting from Mass Products*, 64 MD. L. REV. 613, 688 (2005) (noting that unlike other tort cases, asbestosis and mesothelioma "are 'signature' diseases in which there is a clearly evident and exclusive causal connection" to asbestos exposure).

[172] *See, e.g.*, Margaret A. Berger, *Upsetting the Balance Between Adverse Interests: The Impact of the Supreme Court's Trilogy on Expert Testimony in Toxic Tort Litigation*, 64 L. & CONTEMP. PROB. 289, 298 n.66 (2001).

[173] Gifford*, supra* note 171, at 688.

[174] *See generally* CARROLL ET AL., *supra* note 170.

[175] Grodsky, *supra* note 4, at 1731 n.240.

[176] *Id.* at 1731.

[177] For example, the association between tobacco smoking and cancer derives from studies assessing the incidence of tobacco as a "risk factor" for the development of smoking. *See* WOLFGANG AHRENS & IRIS PIGEOT, HANDBOOK OF EPIDEMIOLOGY 14 (Ahrens Wolfgang & Iris Pigeot eds., 2d ed. 2014) ("One of the milestones in epidemiological research was the development of rigorous case-control designs, which facilitate the investigation of risk factors for chronic diseases with long induction periods. The most famous study of this type, although not the first one, is the study on smoking and lung cancer by Doll and Hill."); *see also* RODOLFO SARACCI, EPIDEMIOLOGY: A VERY SHORT INTRODUCTION 80 (2010). Saracci, an influential epidemiologist, admirably demonstrates the parallelism with the ex-ante and ex-post investigations in the law when he wrote, "The prospective study observes events in their natural course from causes to possible effects. Computing and comparing incidence rates or risks of chronic bronchitis in smokers and non-smokers seeks to answer the question: how often do smokers develop the disease

Therefore, as the focus of many of these studies is forward-looking, there is no reason to postulate that the information available on ex-post probability is systematically superior to the information available on ex-ante probability.[178] Because using ex-ante probability in new generation cases means to speak the same language of many modern scientific studies, in many instances—especially when no signature disease is involved—it will be practically more convenient than investigating ex-ante probability.

It is not my intention to claim that the information available on ex-ante probability is systematically more accurate. Yet, the opposite claim cannot be defended; it cannot be stated *a priori* that information on ex-post probability is always more readily available. That claims regarding ex-ante probability are mere speculations, whereas the ex-post causal link can be assessed in a (quasi) deterministic way, is a myth that should be dispelled.

An additional objection that could be raised is that everyone is exposed to some form of risk in one way or another; thus, admitting compensation for risk would be imposing an excessive burden on the legal system. There are a number of problems with this view. First, this statement clings to the idea that *de minimis* risks should be taken into account. However, applying the same logic to the traditional conception of harm, it is equally true that everyone is harmed in one way or another.[179] For instance, pollution is causing an unlimited number of minimal injuries to each one of us, yet these harms are not cognizable by the law, and rightfully so. I cannot go to a court and demand compensation because I can jog for 50 feet less due to breathing polluted air. Implicit in any legal system is the idea that some *de minimis* harm cannot be compensated. If a similar implicit (or even explicit) threshold is applied to risk, the threat of excessive litigation is already tempered. Second, it is at least dubious that people would sue on the basis of very small risks, as they are associated with very small compensation.

2. When and How to Apply the Pure Probabilistic Approach

I suggest that the pure probabilistic approach ought to be the norm and departures from it are to be grounded only on normative reasons or practical considerations. Incidentally, this is what I advocate with regards to traditional torts.[180] As a practical matter for traditional cases, the deterministic fiction and the ex-post probabilistic approach are generally much easier to handle, and, hence, a switch from the default rule of an ex-ante

compared to non-smokers? A case-control study observes the events in a reverse sequence, from effects to possible causes. It starts from the disease and seeks to answer the question: what proportion of people with chronic bronchitis have been smokers compared to people with no disease?" *Id.*

[178] Robinson, *supra* note 123, at 793.

[179] *See, e.g.*, Rainer v. Union Carbide Corp., 402 F.3d 608, 621 (6th Cir. 2005) ("Accepting the plaintiffs' claim would therefore throw open the possibility of litigation by any person experiencing even the most benign subcellular damage.").

[180] *See* discussion *supra* Section V.A.

framework is justified.

However, the situation is reversed for new generation cases. The deterministic fiction is unworkable, while the objections against an ex-ante probabilistic approach appear untenable without the demon's support. Therefore, for new generation cases, a move from the pure probabilistic approach is justified only in those circumstances in which there is much more information available on ex-post than on ex-ante probability.

The case for an ex-ante probabilistic approach is especially, but not only, compelling for lagged torts.[181] The reason is that the ex-post probabilistic approach is based on a definition of harm that is incompatible with a probabilistic world.[182] As stated above, if it is admitted that (also in principle) we live in a world that can be interpreted only in probabilistic terms, then the asset of a victim should be considered the probability of not getting harmed. Consequently, the harm comes into existence as soon as this probability is reduced, regardless of the moment at which the material harm will emerge. Thus, while the spurious probabilistic approach can be effective for prima facie deterministic instant torts, it is inappropriate for lagged torts. The reason is simple: an ex-post approach becomes effective only after a material harm has taken place. In the case of lagged torts, this circumstance does not arise immediately, and, hence, there will be a certain time interval in which the asset of the patient has already been harmed, but tort law is completely ineffective.

3. The Demon in the Probability

As stated above, embedded in any probabilistic approach, be it spurious or pure, there is a problem of infinite regress.[183] Unless the deterministic fiction is somehow reintroduced into the picture, no compensation can ever be awarded due to the necessarily infinite length of the chain of probabilistic claims. I argue that the demon should be standing at the second step of this chain of probabilistic claims. Harm should be intended in a purely probabilistic sense, and hence be defined in terms of Pr. At the same time, the compensation owed should be scaled down to reflect the accuracy of the probabilistic study. After this additional step, the chain of probabilistic claims should be interrupted.

In practical terms, this solution equates to adopting the proportional approach advocated by the law and economics literature,[184] but incorporating the new definition of harm presented in this work. This solution would

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[181] The problems created by lagged torts with regards to causation are certainly not a new discovery. *See* Robinson, *supra* note 123, at 779–80; *see also* William M. Landes & Richard A. Posner, *Tort Law as a Regulatory Regime for Catastrophic Personal Injuries*, 13 J. LEG. STUD. 417, 427 (1984).

[182] *See infra* notes 184–86 and accompanying text.

[183] *See supra* notes 138–40 and accompanying text.

[184] *See supra* notes 159–63 and accompanying text.

therefore exploit all the efficiencies of the proportional approach identified by the law and economics literature,[185] while adopting a definition of harm that is consistent with the findings of modern science.

VI. CONCLUSION

The literature has debated for decades whether compensation for bare risk should be admitted or a material harm ought to be considered a necessary trigger.[186] Professor Moore suggests that the most powerful argument in favor of the latter option is an experiential one.[187] More precisely, hitting and killing a child feels very different from *almost* hitting and killing a child.[188] Although it is very hard to address arguments based on "gut feelings," I have attempted this task. Professor Moore makes an apparently compelling claim, yet grounded on two fallacies.

First, the parallelism between the two situations is imperfect because Professor Moore adopts an ex-post perspective only regarding risk. It is true that we feel relieved if the risk does not materialize, yet we feel the same relief once the victim is no longer injured. Assume that we hit a child, hurting, but not killing him. Knowing that after a week the child is perfectly healthy and did not suffer any permanent injury will dilute the feeling of guilt. The difference in the feelings in Professor Moore's example is, therefore, primarily due to an asymmetric treatment of risk and harm rather than to ontological differences between the two.

Second, Professor Moore adopts the perspective of the injurer and not that of the victim. Let us assume that five years ago a firm installed a new plant that significantly raised the level of pollution in an area. Assume also that doctors are now able to prove with (almost) absolute certainty that all the people living in the area have a probability of 50% of contracting cancer in the following ten years. Would these people not feel "harmed" upon hearing this news? Or would they think that they are unaffected by this situation until they discover that they belong to the unlucky half of the population?

In short, I believe that even objections based on moral concerns do not fare well against granting risk a greater relevance in the legal arena. Therefore, I argue that a purely probabilistic concept of causation should become the norm, whereas deterministic causation and ex-post probabilistic causations should be considered heuristic tools only when there are practical justifications.

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185 *See* Shavell, *supra* note 12, at 589–90.
186 *See supra* note 18 and accompanying text.
187 *See* MOORE, *supra* note 81, at 29–30.
188 *Id.* at 30.