

**NEGLIGENCE AS OPTIMIZATION PUZZLES:  
A NEW THEORY OF NEGLIGENCE**

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By Issar Birger

Dissertation Committee Supervisor: Professor Richard R.W. Brooks

Readers: Professor Ian Ayres, Professor John Fabian Witt, and Professor Ariel Porat

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## ABSTRACT

This thesis addresses the following questions, among others. Can two people take the exact same precautions yet face different liabilities for identical accidents? Can two people exercise the same overall care yet face different liabilities? Can a person take more precautions than the efficient level of care requires at the time of the accident, yet justifiably be found liable in negligence? More generally, is the Hand Formula economically misguided or inapplicable, at least in many real-world scenarios? Is the Restatement (Third) of Torts equally misguided or imprecise? Is orthodox economic analysis of negligence law predicated and contingent upon over-constrained and unrealistic assumptions? What are the prerequisites for the application of the conventional model of negligence adjudication?

The principle issues examined include (i) Interacting precautions and multidimensional frameworks; (ii) Short-run versus long-run optimization of negligence puzzles; (iii) Path-dependencies and dynamic analysis of care measures; (iv) Non-strictly convex and discontinuous social costs functions; (v) Fluctuating and discontinuous social cost functions; (vi) Threshold effects in costs and efficiency functions; (vii) An expansive methodology to cost-benefit analysis in torts: degrees of freedom, mixed and tailored approaches.

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## INTRODUCTION

Economists and legal theorists have long coalesced around “the most important question that an economic theory of negligence should answer”<sup>1</sup>—how to interpret and apply Judge Hand’s famous  $B < PL$  formula.<sup>2</sup> A marginal approach emerged as the decisive victor of this debate, and for the last three decades was enshrined as the golden standard of negligence law. This dissertation claims that this golden standard is often wrong, must be refined in order to achieve efficiency and is better understood as a special case within a broader framework. It then suggests an alternative view of negligence as optimization puzzles, and an expansive understanding of the Hand Formula. The outcome is a full-scale critical account of the “supply side” of negligence law.

In order to adjudicate even the most basic negligence case, the court must engage in a straightforward cost-benefit analysis, aimed at minimizing the costs of accidents. This analysis is illustrated by the Hand Formula, which calls for the balancing of precaution costs ( $B$ ) on one side, and the costs of expected outcomes ( $PL$ ) on the other. The formula, however, entails some well-known shortcomings. Primarily, it seems to call for the rather insurmountable task of conclusively ascertaining the socially optimal behavior for all settings by measuring the aggregated costs and benefits of all possible sets of precautions. This hurdle impeded many attempts to earnestly apply the Hand Formula, and could have limited its application and reduced it to a mere theoretical principle or ideal.

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<sup>1</sup> Mark F. Grady, *Book Review: Discontinuities and Information Burdens: A review of the Economic Structure of Tort Law by William Landes and Richard Posner*, 56 GEO. WASH. L. REV. 658, 667 (1988) (hereinafter: “*Discontinuities and Information Burdens*”).

<sup>2</sup> *United States v. Carroll Towing Co.* 159 F.2d 169 (2d. Cir. 1947) (hereinafter: “*United States v. Carroll Towing Co.*”).

In an effort to make negligence adjudication manageable, economic scholarship has endorsed the application of a highly narrow and short-run variant of the Hand Formula. This variant, known as the marginal approach, focuses solely upon untaken marginal precautions, and confines negligence inquiry to a single question: “could the defendant have taken a single additional cost-justified precaution?” If the answer to this question is in the affirmative, the defendant should be found negligent. Otherwise, he or she should be deemed to have acted reasonably. Using this technique, the marginal approach attempts to perform a true feat—determine whether the duty of care was breached without actually identifying what the efficient duty of care ought to be. Instead of having the court articulate the required duty in the abstract, the marginal approach provides it with a tool to easily determine whether such duty was in fact breached.

Almost every economic scholar of torts has since embraced the marginal approach, practically without reservation, and affirmed it as the “correct”<sup>3</sup> interpretation of the Hand Formula. From Landes and Posner to Cooter and Ulen, and from Shavell to Grady, the marginal approach was adopted as the golden standard of negligence in both a normative and descriptive sense, and endorsed by the drafters of the RESTATEMENT (THIRD) OF TORTS.<sup>4</sup> Indeed, “a good economist”<sup>5</sup> follows the marginal approach, or so prevailing torts scholarship would have us believe.

This dissertation demonstrates that the marginal approach suffers from a number of fatal flaws, and despite its best intentions, often does more harm than good. Our prime contention is

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<sup>3</sup> William M. Landes and Richard A. Posner, *THE ECONOMIC STRUCTURE OF TORT LAW* 87 (1987) (hereinafter: “*The Economic Structure of Tort Law*”).

<sup>4</sup> See, Robert Cooter and Thomas Ulen, *LAW AND ECONOMICS* 215 (2011) (hereinafter: “*Law and Economics*”) and the discussion of this point in Part I.F hereinafter.

<sup>5</sup> Cooter and Ulen, *ibid*, at p. 214.

that orthodox economic analysis of negligence law is entirely contingent and predicated upon narrowly tailored prerequisites and over-constrained underlying assumptions, and that these assumptions are often unrealistic, exceedingly simplified or plainly misguided. More specifically, the marginal approach quixotically assumes that all precautions are single-dimensional and orthogonal, and overlooks efficiency functions that do not follow the rule of diminishing marginal returns<sup>6</sup> or present with discontinuities, threshold effects and path-dependencies. Rather than accepting the assumptions of the conventional model as given, this thesis systematically relaxes them, and carefully models the impact of doing so on tortfeasors' *ex-ante* and *ex-post* incentives, and on the possibilities of achieving first-best social outcomes.

In most real-world settings, the risk of any detrimental outcome is a product of multiple correlated or interacting actions and omissions.<sup>7</sup> Once a particular precaution is taken, it inevitably affects the efficiency, desirability and normative necessity of taking an additional (marginal) precaution. As a result, the optimal short-run (marginal) outcome is usually path-dependent, contingent on past constraints, susceptible to strategic manipulations and fundamentally diverged from the long-run set of optimal precautions. Additionally, the possibility of taking substitutable sets of different precautions within a multidimensional framework also brings assorted normative difficulties to light, decouples the conventionally

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<sup>6</sup> Under orthodox assumptions, (i) the marginal return on investment in precaution strictly diminishes, so that the expected harm is a monotonically decreasing convex function of investment in precaution; and (ii) the marginal cost of precautions is constant or monotonically increasing. Under these assumptions, the overall cost of accidents is a convex function of investment in precaution. Concurrently, the social benefit or utility of investment in precaution is a concave function. In this dissertation, the term utility function usually refers to social benefit, rather than reduction of harm, and is therefore described under orthodox assumptions as concave rather than convex. We discuss these assumptions in detail in Part II, hereinafter.

<sup>7</sup> In much the same way, multiple correlated risks and beneficial outcomes might result from certain actions and omissions. These too, present a unique risks-aggregation challenge to lawmakers and courts.

assumed link between overall investment in precautions and overall care, and substantially limits the prescriptive value of judicial precedent.

To illustrate the normative difficulties presented by multidimensional and interacting precautions in the context of negligence adjudication, the dissertation views precautionary measures as inputs, and applies classic economic production theory to model their workings. It then constructs a systematic taxonomy of possible relationships between precautions, and classifies them to include: (i) independent (orthogonal) precautions; (ii) complementary precautions; (iii) mutually exclusive precautions; and (iv) interacting precautions, which are further divided between: (a) negatively synergetic precautions; (b) overlapping precautions; and (c) positively synergic precautions. For each type of interaction category, assorted suboptimal equilibria, foreseeable strategic behaviors and inefficiencies are uncovered and discussed. To emphasize the limits of the orthodox analysis, each category is explained by exploring the fact patterns of *Hendricks v. Peabody Co.*,<sup>8</sup> a seminal case originally used to defend the marginal approach in leading economic scholarship.

Furthermore, unlike the assumptions of the conventional model, there is little reason to think that precautions always, or even predominantly, yield continuous and strictly diminishing marginal returns. As this dissertation shows, fluctuating and discontinuous marginal costs and benefit functions, threshold effects and tipping points are actually extremely common in modern negligence settings. When the monotone convexity and continuity assumptions are relaxed, even within a single-dimensional framework, additional normative and practical concerns arise with regards to the application of the Hand Formula. As we shall discuss, this is particularly true when the overall cost of accident function presents with multiple local minima

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<sup>8</sup> 115 Ill. App. 2d 35, 253 N.E.2D (1969) (hereinafter: “the *Hendricks Case*” or “*Hendricks v. Peabody*”).

and equilibria. When the world is seen in this manner—a convoluted tapestry of interactions, path-dependencies and threshold effects—negligence law presents new and unanticipated challenges. For most of these challenges, defaulting to a memoryless and myopic marginal analysis (defined *infra*) is unwarranted, ill advised and frequently harmful.

While showing that the marginal approach is ineffective in ensuring efficient outcomes even under some mundane conditions, the dissertation also discusses the alternative approach to negligence adjudication, known as the aggregated or *in-toto* approach. This approach strives to determine the socially desired level of care based on the accumulated costs and benefits of all possible precautions and foreseeable risks. In other words, it sets out to conclusively find the optimal set of precautions that would yield the minimal social costs for every particular scenario. Using a dynamic model, the thesis establishes that the aggregated approach may also lead to stark inefficiencies resulting from path-dependencies and sunk costs, and is unadministrable by any measure. Specifically, it demonstrates that the aggregated approach may create inefficient short-run incentives when certain past actions are not viewed as constraints, regardless of whether the defendant has previously overinvested or underinvested in precautions. It therefore concludes with finding that the aggregated approach is—in most cases—unfit as a theoretical concept, unsuitable as a normative ideal and inapplicable in practice.

The thesis's aim, however, is broader than deconstructing the foundations of the marginal approach or discarding the underpinnings of the aggregated analysis. It is also to shed light on an important and commonly ignored feature of cost-benefit analysis in torts—an innate and irresolvable tension between short-run and long-run incentives, and between constrained and unconstrained optimization methods: Short-run (marginal) considerations are likely to

incentivize *ex-ante* strategic manipulations, and hinder long-run optimal results. Long-run considerations are likely to induce other detrimental strategic behaviors, and hinder short-run efficient investments. This tension underlies many of the critical models developed throughout the thesis, and the normative dilemmas they present.

Faced with the inadequacies of both the marginal and aggregated analyses, a novel theoretical approach to negligence adjudication is suggested. Rather than being confined to a choice between the aggregated or marginal approach, this thesis proposes considering additional variants of the Hand Formula. In other words, it claims that the aggregated and marginal approach merely represent two extreme ends of a broad spectrum, with a multitude of other approaches or variants lying between them. These variants, referred to as “mixed approaches,” operate as hybrids of marginal and aggregated analyses, and vary with respect to such scales as the length of past timespan considered, the number of conjunctive alternative hypotheticals considered and the nature of the variables reviewed. By applying mixed approaches, lawmakers can perform cost-benefit analyses in torts using varying degrees of freedom, and tailor a specific optimization method to unique challenges, settings, needs and goals. Put differently, the Hand Formula should be conceived as a general framework for minimizing accident costs in optimization puzzles, not a single catchall or “cookie cutter” algorithm.

From this point, the thesis seeks to establish two fundamental principles:

*First*, no one variant of the Hand Formula is perfectly suited to optimize all real-life scenarios, and all such variants might fail to achieve their goals as a result of interacting precautions, threshold effects, temporal changes and sunk costs. For example, “long-run” (and long memory) mixed approaches are less likely to be manipulated by a defendant’s past

strategic behavior, but are more prone to inefficiently consider sunk costs. Short-run (and short memory) mixed approaches, on the other hand, are better equipped to ignore sunk costs when warranted, but are more susceptible to misjudgments resulting from interactions and non-monotonically convex social costs functions.

*Second*, the efficiency goals of tort law can only be achieved—if at all—by specifically tailoring an adjudication method to the unique characteristics of each case, market and technology. As a central element, a court must be mindful of the type of interactions and efficiency functions prevalent in each case, and consider not only the various claims and valuations but also the balancing formula that should be applied. When no such tailoring takes place, and only one variant of the Hand Formula is predictably applied, inefficient results and value destroying strategic behaviors are expected.

Negligence law is therefore best conceived as an exercise in solving optimization puzzles. As this dissertation claims, this is one of the most elusive yet helpful ways to truly understand the law of negligence from an economic perspective. Negligence analysis entails a constant effort to untangle intricate multi-variable scenarios—to find efficient solutions to sometimes immensely complicated events. Many of the problems facing negligence adjudication and theory are plainly or tacitly related to the challenges posed by multidimensional and dynamic optimization puzzles. Surprisingly enough, these challenges have scarcely been considered by legal theory. As a result, our most basic theoretical approach to negligence is theoretically impaired and practically unfitting.

The dissertation unfolds as follows:



Part I presents the two competing approaches to the application of negligence cost-benefit analysis—the marginal and the aggregated approach—and points to the key distinctions between them, such as aim, method, cost, efficiency, reflected timespan and considered evidence. In comparing the two, we find that the marginal approach might lead to efficient yet socially suboptimal conclusions, at least what lumpy precautions are involved, and discuss the informational difficulties associated with applying the aggregated approach. This part then moves to unravel a hidden temporal divergence between the two approaches, and concludes in demonstrating that the marginal approach was widely adopted as the golden standard of negligence adjudication.

Part II reviews the underlying economic assumptions of the conventional model to negligence adjudication, and gives the abovementioned approaches concrete and rigorous economic meanings. Specifically, this part technically defines the injurer's cost-minimization problem under both approaches, and sheds additional light on the key characteristics, fundamental limitations, theoretical prerequisites and methodological processes required for the implementation each approach. While some of the argumentation and proofs presented in this part are already well described in economic literature, the discussion here is novel in separately modeling the two approaches, and in explicating the necessary and sufficient conditions for their implementation. Part II concludes with a table summarizing the economic differences between the marginal and aggregated approach.

Parts III and IV are principally dedicated to relaxing the underlying assumptions of the conventional model, and to a critical exploration of the theoretical implications of doing so. They progress as follows: Part III focuses on relaxing the convexity, monotonicity and continuity assumptions. Principally, it studies the impact of thresholds, tipping points and

network effects on the theory of negligence, and exemplifies their influence using two real-world examples: smoking addiction and epidemic dynamics. This part then continues to discuss the normative implications of relaxing the above assumptions, and characterizes two unique types of cases: (i) local minima anteceding to the global optimum, and (ii) local minima postliminar to the global optimum (both cases defined *infra*). For each type of case, distinctive normative difficulties to the application of the Hand Formula are uncovered, and possible realistic scenarios for their occurrence are hypothesized. Part III concludes by pointing to additional impasses associated with short-run versus long-run optimization, and reflecting on the fragility of the conventional model in connection to the Anna Karenina Principle, discussed there.

Part IV adds an additional layer of complexity and realism, and relaxes the single dimensionality and orthogonality and predeterminacy assumptions. This part begins by relaxing the single dimensionality assumption, and demonstrates the multidimensional nature of real-world negligence settings. In doing so, it shows that different precautions are often substitutable, and explores the ramifications that quality exerts upon negligence adjudication. This part then provides a systematic account of the precaution side of the Hand Formula, principally applying tools and terms developed in microeconomic production theory. It then explores the normative difficulties brought about by multidimensional settings, and illustrates these difficulties in caselaw. The first portion of Part IV concludes in reflecting upon variable selection, specific versus general regulation and short-run versus long-run optimization in the context of multidimensionality.

Part IV then continues to relax the orthogonality assumption, and introduces the possibility of interacting or correlated precautions. It moves to systematically categorize

possible relationships between precautions, and models the potential adverse effects and challenges to negligence adjudication they present. For each type of interaction, assorted suboptimal equilibria, foreseeable strategic behaviors and inefficiencies expected from a misguided application of the Hand Formula are uncovered and illustrated. As a major focus, the second portion of Part IV attempts to provide a broad account of the effect of path-dependencies on different forms of negligence analyses, and illustrates the implications of memoryless, semi-constrained and myopic algorithms on tortfeasors *ex-ante* and *ex-post* incentives. Part IV concludes with a discussion of the conditions for commensurating multidimensional precautions.

Part V presents a model of mixed approaches to the application of the Hand Formula, and suggests an expansive rubric for negligence adjudication, founded upon tailoring optimization processes to particular settings. It then continues to substantiate an impossibility theorem, according to which no single variant of the Hand Formula is perfectly suited to optimize all settings. Finally, it addresses optimization costs and the pleading systems, and posits that, in reality, different standards of negligence or scrutiny are applied to low-stake and high-stake litigants, and that such difference might be justified on efficiency grounds. Part V concludes with a discussion of the relationship between activity level variables and mixed approaches, and the possibility of setting the standard of care assuming certain optimal prior precautions have been taken.

Part VI concludes.

**PART I:**  
**COST-BENEFIT ANALYSIS IN NEGLIGENCE LAW**

**A. THE ECONOMIC RATIONAL OF NEGLIGENCE LAW AND THE HAND FORMULA**

According to conventional wisdom in law and economics, the normative goal of negligence law is to maximize social welfare by reducing the overall cost of accidents, *i.e.* the sum costs of precautions and materialized harms.<sup>9</sup> This principle requires parties to apply a rational cost-benefit analysis aimed at optimally investing in precautions: a burden often easier said than done. The difficulties involved in performing this cost-benefit evaluation underlie some of the most difficult questions in the law of negligence.

In its simplest form, negligence law mandates that a tortfeasor be liable for the harm caused to her victim, if that harm resulted from the tortfeasor's failure to take due care. Due care, sometimes referred to as ordinary or reasonable care, is the legal standard stipulating the minimally required level of precaution.<sup>10</sup> If an injurer exercises precaution at a level lower than that required by due care, and such failure was the proximate cause of harm, he or she will be found liable.<sup>11</sup>

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<sup>9</sup> For a seminal analysis see Guido Calabresi, *THE COST OF ACCIDENTS* (1970) (hereinafter: "*The Cost of Accidents*"); Cooter and Ulen, *Law and Economics*, *supra* note 4, at p. 200-201; and Landes and Posner, *The Economic Structure of Tort Law*, *supra* note 3.

<sup>10</sup> For a classic definition see *Brown v. Kendall*, 60 MASS. 292 (1850) (hereinafter: "*Brown v. Kendall*"): "[Ordinary care] means that kind and degree of care, which prudent and cautious men would use, such as is required by the exigency of the case, and such as is necessary to guard against probably danger."

<sup>11</sup> For simplicity, we ignore contributory negligence throughout this thesis and address, without loss of generality, unilateral precautions only, meaning scenarios where only one player can take precautionary measures. We further limit our analysis to the "precaution side" of breach of duty element, and generally apply a neoclassical economics framework, rather than non-economic or behavioral approaches. In this sense, our discussion focuses on the most basic or hylic state and understandings of the Hand Formula.

Setting the optimal level of due care is thus pivotal to law's aim of maximizing social welfare. If the bar is set too high, inefficient investments in precaution will occur, and parties might decide to refrain from a socially desirable activity or pull out of a market altogether. If the bar is set too low, suboptimal investment in precautions is expected, and it is possible that socially inefficient or undesirable activities will persist.<sup>12</sup> Conducting a negligence inquiry or judicially setting the optimal level of care is, however, far more complicated than it appears.

Pursuant to *United States v. Carroll Towing Co.*,<sup>13</sup> the reasonableness of a party's behavior is judged by lawmakers according to the Hand Formula, which states that a party is in breach of duty if his or her burden of precaution ( $B$ ) was lower than the probability of harm ( $P$ ) times the gravity of resulting injury ( $L$ ).<sup>14</sup> This formula is incorporated in the definition of negligence offered by the RESTATEMENT (THIRD) OF TORTS,<sup>15</sup> and endorsed nearly without

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<sup>12</sup> Assuming generally acceptable economic assumptions, such as that people are rational and adjust their behavior according to legal rules. On miscalculations in setting the level of due care see, for instance, Richard Craswell, *Deterrence and Uncertain Legal Standards*, 2 J. LAW, ECON & ORGANIZATION 279 (1986); and Steven Shavell, ECONOMIC ANALYSIS OF ACCIDENT LAW 79-83 (1987) (hereinafter: "*Economic Analysis of Accident Law*").

<sup>13</sup> *Supra* note 2.

<sup>14</sup> In Judge's Hand words: "...[T]he owner's duty, as in other similar situations, to provide against resulting injuries is a function of three variables: (1) the probability that she will break away; (2) the gravity of the resulting injury, if she does; (3) the burden of adequate precautions. Possibly it serves to bring this notion into relief to state it in algebraic terms: if the probability be called  $P$ ; the injury  $L$ ; and the burden,  $B$ ; liability depends upon whether  $B$  is less than  $L$  multiplied by  $P$ , i.e., whether  $B < PL$ ..." (*United States v. Carroll Towing Co.*, *ibid*, at p. 173).

<sup>15</sup> RESTATEMENT (THIRD) OF TORTS: PHYS. & EMOT. HARM § 3 (2010), stating: "A person acts negligently if the person does not exercise reasonable care under all the circumstances. Primary factors to consider in ascertaining whether the person's conduct lacks reasonable care are the foreseeable likelihood that the person's conduct will result in harm, the foreseeable severity of any harm that may ensue, and the burden of precautions to eliminate or reduce the risk of harm." As *Comment e* states, "insofar as this Section identifies primary factors for ascertaining negligence, it can be said to suggest a 'risk-benefit test' for negligence... The test can also be called a 'cost-benefit test'... Overall, this Section can be referred to as supporting a 'balancing approach' to negligence." *Comment e* continues to note that, "The actor's conduct is hence negligent if the magnitude of the risk outweighs the burden of risk prevention." The Reporters' Notes to *Comment d* also makes clear that the RESTATEMENT (SECOND) OF TORTS §291-296 (1965) also "explicitly adopt[s] a balancing approach by calling for weighing the magnitude of the risk against the utility of the actor's conduct and the burden of avoiding the risk."

On the test prescribed by the restatement and its relation to the Hand Formula see Stephen G. Gilles, *On Determining Negligence: Hand Formula Balancing, the Reasonable Person Standard, and the Jury*, 54 VAND. L. REV. 813 (2001) (hereinafter: "*On determining Negligence*"); Michael D. Green, *W. Page Keeton Symposium on Tort Law: Negligence = Economic Efficiency: Doubts >*, 75 TEX L. REV. 1605 (1997) (hereinafter: "*Negligence = Economic*

reservation in law and economic scholarship as a “unifying perspective in which to view all of tort law.”<sup>16</sup> Though the extent of its application by courts remains disputed,<sup>17</sup> this “centerpiece of [] conventional economic theory”<sup>18</sup> is widely considered an accurate exemplification of the economic theory of negligence—the crux of negligence law.<sup>19</sup> To quote Feldman and Kim:

“Judge Learned Hand’s opinion in *United States v. Carroll Towing Co.* is canonized in the law-and-economics literature. It is like the opening measure of Beethoven’s Fifth Symphony, or the third line of the Bible: ‘And God said, Let there be light.’”<sup>20</sup>

Despite its simplicity and appeal, the application of the Hand Formula involves some well-known shortcomings. Primarily, it fails to account for players’ activity level, as well as other behaviors that are non-observable, non-verifiable or simply too costly to be considered

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*Efficiency: Doubts >*”); Kenneth W. Simons, *The Hand Formula in the Draft Restatement Third of Torts: Encompassing Fairness As Well As Efficiency Values*, 54 VAND. L. REV. 901 (2001) (hereinafter: “*The Hand Formula in the Draft Restatement Third of Torts*”); and Steven Hetcher, *The Jury’s Out: Social Norms’ Misunderstood Role in Negligence Law*, 91 GEO. L.J. 633 (2003).

<sup>16</sup> Richard A. Posner, TORT LAW—CASES AND ECONOMIC ANALYSIS 2 (1982) (hereinafter: “*Cases and Economic Analysis*”); See also William M. Landes and Richard A. Posner, THE ECONOMIC STRUCTURE OF TORT LAW (1987); Shavell, *Economic Analysis of Accident Law*, *supra* note 12; and *infra* notes 85-97 in Section I.F.

<sup>17</sup> For a claim that the Hand Formula is inconsistent with the actual criteria applied by courts see Richard W. Wright, *Hand, Posner, and the Myth of the “Hand Formula*, 4 THEORETICAL INQUIRIES L. 145 (2003) (hereinafter: “*Hand, Posner, and the Myth of the “Hand Formula*”). See also Stephen G. Gilles, *The Invisible Hand Formula*, 80 VA. L. REV. 1015 (1994), and the sources mentioned in footnotes 4-5 there.

<sup>18</sup> Mark F. Grady, *Untaken Precautions*, 18 J. LEGAL STUD. 139, 147 (1989) (hereinafter: “*Untaken Precautions*”).

<sup>19</sup> For doctrinal authority and reflection see, Dan B. Dobbs, THE LAW OF TORTS §§ 144-146 (2000); John G. Fleming, THE LAW OF TORTS 114-119 (8<sup>th</sup> ed., 1992); Michael A. Jones, TEXTBOOK ON TORTS § 3.1.3.3 (7<sup>th</sup> ed., 2000); W. Page Keeton, Dan B. Dobbs, Robert E. Keeton and David G. Owen, PROSSER AND KEETON ON THE LAW OF TORTS 170-173 (5<sup>th</sup> ed., 1984); W.V.H. Rogers, Winfield and Jolowicz ON TORT 201-202 (16<sup>th</sup> ed. 2002); and Patrick J. Kelley, *Teaching Torts: The Carroll Towing Company Case and the Teaching of Tort Law*, 45 ST. L. U. L.J. 731, 732-735 (2001). See also the Reporters’ Notes to the RESTATEMENT (THIRD) OF TORTS summarizes, “[a] balancing approach to negligence has been accepted in judicial opinions in a large majority of jurisdictions” (RESTATEMENT (THIRD) OF TORTS: PHYS. & EMOT. HARM § 3 (2010), Reporters’ Notes on *Comment d*). For an historical perspective on the use and implementation of the Hand Formula see Richard A. Posner, *A Theory of Negligence*, 1 J. LEGAL STUD. 29 (1972) (hereinafter: “*A Theory of Negligence*”), but compare Henry T. Terry, *Negligence*, 29 HARV. L. REV. 40 (1915).

<sup>20</sup> Allan M. Feldman and Jeonghyun Kim, *The Hand Rule and United States v. Carrol Towing Co. Reconsidered*, 7 AMERICAN L. ECON. REV. 523-524 (2005).

judicially.<sup>21</sup> It also faces difficulties with variable selection,<sup>22</sup> as well as functional and fundamental difficulties in assessing the value of each of its components.<sup>23</sup> Additionally, it may also fail to take into account various secondary consequences, such as positive externalities derived from setting precedents. Finally, as Cooter and Porat note,<sup>24</sup> courts have persistently erred in the application of the Hand Formula, by ignoring the element of risk to the defendant or the full spectrum of risks to the plaintiff.<sup>25</sup>

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<sup>21</sup> On the prolific writing regarding activity levels see Steven Shavell, *Strict Liability versus Negligence*, 9 J. LEGAL STUD. 1 (1980) (hereinafter: “*Strict Liability versus Negligence*”); Shavell, *Economic Analysis of Accident Law*, *supra* note 12, at p. 25; Steven Shavell, *Torts in Which Victim and Injurer Act Sequentially*, 26 J. LEGAL STUD. 589 (1983); Calabresi, *The Costs of Accidents*, *supra* note 9, at pp. 108-109, 259-261; Cooter and Ulen, *Law and Economics*, *supra* note 4, at p. 211; Landes and Posner, *The Economic Structure of Tort Law*, *supra* note 3, at p. 61, 66; William M. Landes and Richard A. Posner, *The Positive Economic Theory of Tort Law*, 15 GEO. L. REV. 851, 875-8 (1981); William M. Landes and Richard A. Posner, *Joint and Multiple Tortfeasors: An Economic Analysis*, 9 J. LEGAL STUD. 517 (1980); Richard A. Posner, *Strict Liability: A Comment*, 2 J. LEGAL STUD. 250 (1973); Posner, *Cases and Economic Analysis*, *supra* note 16, at p. 5; Stephen G. Gilles, *Rule-based Negligence and the Regulation of Activity Levels*, 21 J. LEGAL STUD. 319 (1992) (hereinafter: “*Rule-based Negligence and the Regulation of Activity Levels*”); Louis Kaplow and Steven Shavell, *Economic Analysis of Law*, in HANDBOOK OF PUBLIC ECONOMICS (Alan J. Haverbrack and Martin S. Feldstein eds., 2002); Howard Latin, *Activity Levels, Due Care, and the Selective Realism in Economic Analysis of Tort Law*, 39 RUTGERS L. REV. 487 (1987); Shawn J. Bayern, *The Limits of Formal Economics in Tort Law: The Puzzle of Negligence*, 75 BROOKLYN L. REV. 707 (2010) (hereinafter: “*The Limits of Formal Economics in Tort Law: The Puzzle of Negligence*”); John J. Donohue, *The Law and Economics of Tort Law: The Profound Revolution*, 102 HARV. L. REV. 1047 (1989); and Donald Wittman, *Optimal Pricing of Sequential Inputs: Last Clear Chance, Mitigation of Damages, and Related Doctrines in the Law*, 10 J. LEGAL STUD. 65 (1981). For further discussion of activity level in the negligence context see Section V.F. hereinafter, and *infra* notes 339-350.

<sup>22</sup> On variable selection in the context of the Hand Formula see James M. Anderson, *The Missing Theory of Variable Selection in the Economic Analysis of Tort Law*, UTAH L. REV. 255 (2007) (hereinafter: “*The Missing Theory of Variable Selection*”); Giuseppe Dari-Mattiacci, *On the Optimal Scope of Negligence*, 1 REV. L. ECON. 331 (2005) (Hereinafter: “*On the Optimal Scope of Negligence*”); and our discussion in Section IV.B.g. hereinafter.

<sup>23</sup> For the fundamental difficulties in performing this evaluation see, for example, R. M. Dworkin, A MATTER OF PRINCIPLE 237-266 (Cambridge, Mass., 1985); G. Calabresi, *About Law and Economics: A Letter to Ronald Dworkin*, 8 HOFSTRA L. REV. 552 (1980); R. M. Dworkin, *Why Efficiency? – A Response to Professors Calabresi and Posner*, 8 HOFSTRA L. REV. 563 (1980); and Warren A. Seavey, *Mr. Justice Cardozo and the Law of Torts*, 39 COLUM. L. REV. 20, 34 (1939) (memorably noting, “[I]f you kidnap a child and, while driving carefully away with it, run down a pedestrian, you will not be liable in negligence for the pedestrian’s injury”).

<sup>24</sup> Robert Cooter and Ariel Porat, *Does Risk to Oneself Increase the Care Owed to Others?*, 29 J. LEGAL STUD. 19 (2000) (hereinafter: “*Does Risk to Oneself Increase the Care Owed to Others?*”). See also Kenneth W. Simons, *The Puzzling Doctrine of Contributory Negligence*, 16 CARDOZO L. REV. 1693, 1725-1728 (1995) and RESTATEMENT (THIRD) OF TORTS: PHYS. & EMOT. HARM § 3 (2010), *comment b* and Reporters’ Note. For further discussion on these points see, Ariel Porat, *Misalignments in Tort Law*, 121 YALE L.J. 82 (2011) (hereinafter: “*Misalignments*”) and our Section IV.B.f hereinafter.

<sup>25</sup> For additional difficulties associated with the application of the Hand Formula and its limitations see Section IV.B.a and *infra* notes 186-199.

This thesis points to additional fundamental difficulties to the application of the Hand Formula, and in some respects to its basic configuration, which have generally eluded legal scholarship. Ironically, the adverse effects of these difficulties are exacerbated when law and economics' prescribed best practices are applied, and when lawmakers defer to the judgment and teachings of conventional wisdom.<sup>26</sup>

## **B. TWO APPROACHES TO THE APPLICATION OF NEGLIGENCE COST-BENEFIT ANALYSIS**

In establishing the reasonable level of care and conducting cost-benefit inquiry in light of the Hand Formula, negligence law has grappled between two competing approaches: the aggregated (*in-toto*) approach on the one hand, and the marginal (“precaution not-taken”) approach on the other.<sup>27</sup> This key divergence has been reflected in the common law from early on. The two approaches differ on a variety of scales and perspectives, such as objective, method, application costs, evidence considered, efficiency of outcome and often the timespan reviewed. With regards to most of these factors, law and economics scholarship has taken, I believe, an overly decisive stand in favor of the marginal approach.

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<sup>26</sup> On this term see, John Kenneth Galbraith, *THE AFFLUENT SOCIETY* 6-18 (Mariner Books; 40 Anv. sub. ed., 1958) (famously coining the phrase conventional wisdom, and arguing that when faced with the complexities of economic and social behavior, people adhere to what is convenient and simple, even if not necessarily true).

<sup>27</sup> For a different categorization, pertinent to strategic settings, see Feldman and Kim, *The Hand Rule and United States v. Carrol Towing Co. Reconsidered*, *supra* note 20, at p. 527.



a. **THE AGGREGATED APPROACH**

The aggregated (*in-toto*) approach, sometimes referred to as the conventional theory or the  $P^*$ -comparison approach,<sup>28</sup> aims to find the optimal level of care for each type of activity, taking into account the overall costs of precautions and risks. According to this method, the optimal level of care is determined based on the cost of all adequate precautions, taken or untaken, aggregated and weighed together against the expected costs of all foreseeable risks.<sup>29</sup>

What this means in practice is that courts must identify abstractly the “most technically efficient precautions for every accident”.<sup>30</sup> In other words, courts must seek to identify the combination of care-measures that would yield the global minimum of social costs. The product of this process is a conclusive level of care, denoted  $x^*$  or sometimes  $p^*$ , to which prospective tortfeasors must conform.<sup>31</sup> When they do, the social costs of accidents should theoretically be minimized. When they do not meet that care threshold, the costs of accidents will be higher than optimal, and the relevant tortfeasors will face liability.<sup>32</sup>

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<sup>28</sup> Mark F. Grady, *A New Positive Economic Theory of Negligence*, 92 YALE L.J. 101, 104 (1983) (hereinafter: “*A New Positive Economic Theory of Negligence*”).

<sup>29</sup> Generally, some variables and elements are excluded from consideration even under an aggregated analysis. Excluded variables and elements are usually labeled “activity level”, though it is sometimes hard to substantiate this difference on ontological or intuitive grounds. On this distinction, which will be further addressed hereinafter, see Dari-Mattiacci, *On the Optimal Scope of Negligence*, *supra* note 22; Peter A. Diamond, *Single Activity Accidents*, 2 J. LEGAL STUD. 107 (1974); and our discussion in Section V.F.

<sup>30</sup> Grady, *Discontinuities and Information Burdens*, *supra* note 1, at p. 660.

<sup>31</sup> See, Cooter and Ulen, *Law and Economics*, *supra* note 4, at p. 196; and Landes and Posner, *The Economic Structure of Tort Law*, *supra* note 3.  $\bar{x}$  usually denotes the legal standard, while  $x^*$  denotes the socially optimal level of care. Ideally, the legal aim is for  $\bar{x}$  to equal  $x^*$ .

<sup>32</sup> This approach coincides with certain aspects, though not all, of the traditional theory of common law negligence. Holmes, for instance, noted that the role of judges is to find “the set of actual precautions that must be taken in different accident situations.” See Oliver Wendell Holmes, JR., THE COMMON LAW 124 (1881) (hereinafter: “*The Common Law*”); Grady, *Discontinuities and Information Burdens*, *supra* note 1, at p. 662 (discussing Holmes); and Grady, *Untaken Precautions*, *supra* note 18, at p. 142.

In some ways, the aggregated approach results in placing courts in the shoes of regulators. A good aggregated judgment, much like a good regulatory act, produces a specific list of necessary precautions and behaviors, or at least a minimally required investment level.<sup>33</sup> Based on this list, prospective players would ideally know how to conduct themselves in order to avoid liability, and what the law expects of them while engaging in specific activities. From a broader viewpoint, a judicial body of detailed precedents should eventually have the same effect as regulation, and form a clear, comprehensive and well-established due care level for all types of recurring activities.<sup>34</sup>

The aggregated approach envisions highly detailed judgments, and a constant striving by courts to give concrete meaning to the duty of care on a case-by-case basis. It requires court to “establish the (external and objective) standard of care for the accident at hand, [and] then [] measure the actor’s conduct against it.”<sup>35</sup> This form of measurement and comparison is deeply rooted in the Common Law. As Holmes noted:

“[T]he featureless generality, that the defendant was bound to use such care as a prudent man would do under the circumstances, ought to be continually giving place to the specific one, that he was bound to use this or that precaution under these or those circumstances.”<sup>36</sup>

The obvious difficulty with the aggregated approach is that it necessitates ample and sometimes excessive information, technical expertise and deliberation by courts.<sup>37</sup> It is also no

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<sup>33</sup> On this distinction, and the conditions for commensurating multidimensional precautions along a single axis, see in Section IV.D. hereinafter.

<sup>34</sup> Compare, Samuel Issacharoff and John F. Witt, *The Inevitability of Aggregate Settlement: An institutional Account of American Tort Law*, 57 VAND. L. REV. 1571 (2004) (hereinafter: “*The Inevitability of Aggregate Settlement*”).

<sup>35</sup> Grady, *Untaken Precautions*, *supra* note 18, at p. 142.

<sup>36</sup> Holmes, *The Common Law*, *supra* note 32, at p. 111. See also Francis H. Bohlen, *Mixed Questions of Law and Fact*, 72 U. PA. L. REV. 111 (1924) and Green, *Negligence = Economic Efficiency: Doubts >*, *supra* note 15, at pp. 1625-1626.

<sup>37</sup> Grady, *Discontinuities and Information Burdens*, *supra* note 1, at p. 660.

always clear what information, behaviors and timespan are relevant and should be taken into account in performing an aggregated inquiry.<sup>38</sup> These features make the aggregated approach almost unmanageable, and in any case extremely expensive to implement. Courts do not possess the same knowledge, familiarity and scientific discovery processes as regulatory agencies. By nature of the adversarial process, courts are also inherently limited to consider only information provided by the parties. In reality, as noted by Guttel, “determining the optimal level of care in a particular case... demands data that courts are frequently unable to obtain.”<sup>39</sup>

This “information problem” is well ingrained in tort theory. Brown, a forerunner of economic modeling of negligence law, noted that even his simple-version equations of aggregated analysis would require courts to “ferret out complete information about the underlying technology of accident prevention.”<sup>40</sup> He further commented that his aggregated model would require judges to be engineers.<sup>41</sup> Grady similarly noted that “[i]t would often be Herculean for courts to determine what combination of different precautions minimizes a social cost that consists of a constellation of different foreseeable risks. Frequently... courts would not have enough information for the task.”<sup>42</sup> The information problem is, indeed, the fundamental weakness of the aggregated approach, and the reason for the development of an alternative solution to or theory of negligence adjudication—the marginal approach.<sup>43</sup>

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<sup>38</sup> See hereinafter, in Part IV.

<sup>39</sup> Ehud Guttel, *The (Hidden) Risk of Opportunistic Precautions*, 93 VIRGINIA L. REV. 1389, 1395 (2007) (hereinafter: “*The (Hidden) Risk of Opportunistic Precautions*”). As this thesis will soon demonstrate, the aggregated approach suffers from other fundamental flaws, associated amongst others with path dependencies and sunk costs.

<sup>40</sup> John P. Brown, *Towards an Economic Theory of Liability*, 2 J. LEGAL STUD. 323, 333 (1973).

<sup>41</sup> Brown, *ibid*, at p. 333-334.

<sup>42</sup> Grady, *Untaken Precautions*, *supra* note 18, at p. 147.

<sup>43</sup> As we further explore in Part IV, it is possible to set an aggregated standard in the abstract, rather than in the

## b. THE MARGINAL APPROACH

The marginal approach, also known as the precaution not-taken approach,<sup>44</sup> operates in a very different way than the aggregated approach. It does not strive to set a comprehensive level of care in the abstract or stipulate an optimal or minimal set of precautions a prospective tortfeasor must take. In fact, it is not interested in directly prescribing any highly specified duties. Rather, the marginal approach merely examines whether a defendant was negligent in a particular case by comparing the cost of any precaution not-taken pleaded by the plaintiff to the costs that could have been avoided by taking that precaution. If the plaintiff can point to an untaken cost-justified precaution, the defendant will be found negligent for not taking that precaution.<sup>45</sup> Putting this difference of method figuratively, where an aggregated approach would ask for two sugars, a marginal approach would just “say when.”<sup>46</sup>

As a result, the marginal approach generally ignores all past actions and investments and all possible contingencies pertaining to the future, and considers only whether the defendant could have taken a single additional cost-justified precaution. It takes no note of the defendant’s overall investment level and disregards her past actions and best efforts to avoid

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form of specific precautions that must be taken. The analytical divergence between the two and its significance will become clear in our discussion there.

<sup>44</sup> Grady distinguished between a precaution not-taken approach and a marginal approach. This distinction goes mainly to the problem of discontinuous liability problem in negligence law, and is not directly related to the subject matter of this dissertation. See, Grady, *Discontinuities and Information Burdens*, *supra* note 1, and Grady, *A New Positive Economic Theory of Negligence*, *supra* note 28. See also Robert D. Cooter, *Economic Analysis of Punitive Damages*, 56 S. CAL. REV. 100 (1982); and John E. Calfee and Richard Craswell, *Some Effects of Uncertainty on Compliance with Legal Standards*, 70 VA. L. REV. 965 (1984).

<sup>45</sup> Naturally, other elements of negligence, such as causation and harm, must also be met for liability to arise.

<sup>46</sup> For a related debate, within the broader context of property versus liability rules see Richard R.W. Brooks, *The Relative Burden of Determining Property Rules and Liability Rules: Broken Elevators in the Cathedral*, 97 NW. U.L. REV. 267 (2002). See also Richard A. Posner *ECONOMIC ANALYSIS OF LAW* 77-78 (2011) (hereinafter: “*Economic Analysis of Law*”) (arguing the merits of property rules by noting, “just as it is easier to determine whether one person is taller or heavier than another than it is to determine how tall or heavy either person is.”).

negligent behavior. It maintains one simple rule: if the plaintiff can show the existence of a marginally efficient precaution that was not taken by the defendant, negligence should be inferred.<sup>47</sup>

The economic principle underlying the marginal approach is one of diminishing marginal returns. According to this principle, the benefit derived from any marginal investment in precaution continuously diminishes. When that is the case, the overall utility function of the relevant precaution should have a single “tilting point”, beyond which additional investment would be inefficient. Up to this tilting point, investment in precaution is warranted. Beyond this point, the cost of any additional investment in precaution will not justify the derived benefit. This tilting point reflects, according to classic theory, the socially optimal investment level, or due care. As Guttel explains:

“Highlighting the economic reasoning underlying the [Hand] formula, legal theorists have argued that resolving questions of liability on the basis of the efficiency of the litigant’s untaken precautions induces optimal care. In order to avoid liability, rational parties will invest in precautions up to the point that no additional, cost-justified precaution exist.”<sup>48</sup>

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<sup>47</sup> Cooter and Ulen elegantly summarized the gist of the marginal approach, noting:

“The marginal Hand rule states that the injurer is negligent if the marginal cost of his or her precaution is less than the resulting marginal benefit. Thus, the injurer is liable under the Hand rule when further precaution is cost-justified” (Cooter and Ulen, *Law and Economics*, *supra* note 4, at p. 214).

It is worth noting that, generally speaking, the further the defendant is from the optimal level of care, the more options the plaintiff will typically have to claim negligence, and the higher the chances of harm. On this point, see Grady, *Untaken Precautions*, *supra* note 18, at p. 144.

<sup>48</sup> Guttel, *The (Hidden) Risk of Opportunistic Precautions*, *supra* note 39, at p. 1391. Cooter and Ulen provide a similar, though more technical, explanation:

“If precaution is less than the efficient amount, then the marginal social cost of precaution is less than the marginal social benefit:  $(x < x^*) \rightarrow (\omega < (p'[x^*]A))$ . When the marginal social cost of precaution is less than the marginal social benefit, efficiency requires taking more precaution. In these circumstances, we say that more precaution is ‘cost-justified’. Similarly, if precaution exceeds the efficient amount, then the marginal social cost of precaution exceeds the marginal social benefit:  $(x > x^*) \rightarrow (\omega > (p'[x^*]A))$ . In these circumstances, efficiency requires taking less precaution.” (Cooter and Ulen, *Law and Economics*, *supra* note 4, at p. 201).

Based on this idea, the main advantage of the marginal approach becomes clear: it solves the information problem associated with the aggregated approach, or at least substantially relaxes it.<sup>49</sup> By applying a marginal analysis, courts now seem to be able to perform the impossible—determine whether the defendant has met the efficient investment level without actually identifying or knowing what that level is. Simply examining whether the defendant could have taken an additional cost-justified precaution is thought to be sufficient.<sup>50</sup>

This is truly an exciting find, no less than a wonder. If true, as assumed by prevailing scholarship, it would make the marginal approach adequate and satisfactory for negligence adjudication, and circumvent the need for excessive information and expansive judicial inquiries. Grady, one of the chief advocates of the precaution not-taken approach, captured this strength by noting that:

“The same untaken-precaution approach also reduces courts’ need for technical information because they no longer have to identify the precautions that produce the global minimum of social cost; they need only examine the costs and benefits of the precautions that the plaintiff has actually alleged that

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See also, John P. Brown, *Learned Hand Rule*, in THE NEW PALGRAVE DICTIONARY OF ECONOMICS AND THE LAW 514, 514-516 (Peter Newman ed., 1998) (hereinafter: “*Learned Hand Rule*”).

<sup>49</sup> For other advantages attributed to the marginal approach, specifically in the context of uncertainty see Grady, *A New Positive Economic Theory of Negligence*, *supra* note 28, at p. 123.

<sup>50</sup> In Grady’s words:

“Probably the best way for an injurer to assess whether he is at  $P^*$  [the optimal level of care] would be for him to consider whether there are any further precautions—beyond those currently planned or taken—that would reduce expected harm by a greater amount than the cost that they would impose. This is also the most plausible way by which a court could determine whether an injurer was taking less than  $P^*$ .” (Grady, *A New Positive Economic Theory of Negligence*, *ibid.*, at p. 111).

Similarly, Brown notes:

“[i]t is not necessary to identify the standard of care; it is sufficient to determine whether or not the standard of was met. Of course, one way for a plaintiff to meet his responsibility and show that a duty was breached is to find a precaution untaken, which, if taken, would have had a greater marginal benefit than its marginal cost.” (Brown, *Learned Hand Rule*, *supra* note 48, at p. 516).

the defendant failed to take. Untaken precautions beyond the efficient set appear cost-beneficial only when the injurer has used less precaution than due care. When the injurer has used the most efficient precautions, as he has an incentive to do, no further precaution will appear cost-beneficial.”<sup>51</sup>

In this regard, it is worth noting three key features of the marginal approach. *First*, it calls for an adjudication process by which “courts examine the desirability of each untaken precaution *individually*”,<sup>52</sup> as opposed to untaken combinations of (multiple) precautions. *Second*, only *additional* precautions—“beyond those currently planned or taken”<sup>53</sup>—are considered. *Third*, it assumes that precautions present with an overall continuous, monotonically decreasing and convex efficiency function, meaning that the marginal reduction of harm derived from additional investments in precautions strictly diminishes. In other words, it assumes that the total utility function of investing in precautions is continuous and strictly concave.<sup>54</sup>

These three features are central to the understanding, value and usefulness of the marginal approach, and set it apart from the aggregated approach. Without these features, the marginal approach loses its edge over the aggregated analysis. In order to avoid an endless odyssey of comparing the overall efficiency and costs of all possible combinations of precautions, taken or untaken at any time, the marginal approach focuses only on an *individual* (marginal, last) precaution *not* taken; and presupposes a concave overall utility function. This

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<sup>51</sup> Grady, *Discontinuities and Information Burdens*, *supra* note 1, at p. 661.

<sup>52</sup> Grady, *ibid*, at p. 660 (emphasis added). We further discuss this feature in Part IV, within the context of myopic algorithms and forward-looking inefficiencies.

<sup>53</sup> Grady, *A New Positive Economic Theory of Negligence*, *supra* note 28, at p. 111. We further discuss this feature in Part IV, within the context of memoryless algorithms and backward-looking inefficiencies.

<sup>54</sup> Not all three attributes are always explicit in literature, particularly with regards to viewing past actions as constraints; see, Green, *Negligence = Economic Efficiency: Doubt >*, *supra* note 15, at pp. 1612-1614. We discuss variants of the Hand Formula and the significance of the divide between past variables and constraints hereinafter, in Part V.

focus is what grants the marginal approach the ability to overcome the magnitude of the information problem. As this research will soon show, it is also its Achilles Heel.

Finally, while the marginal approach does not aim to set a comprehensive and prescriptive level of due care based on one particular judgment, a prevalent view in torts scholarship is that “[r]epeated application of the [marginal] Hand rule enables adjudicators to discover the efficient level of care.”<sup>55</sup> This view is based on two assumptions: (i) that courts can correctly implement the marginal approach, and (ii) that the relevant market perfectly reacts to judicial rulings.

When these two assumptions are met, repeated judicial application of the marginal approach over similar cases should incentivize players to continuously increase their investment in precautions to exceed any investment level previously adjudicated as insufficient. In a recursive process, potential tortfeasors should efficiently increase their investment in precaution until they reach the point where further expenditures will no longer be mandated by the courts, *i.e.* will not be cost-justified.<sup>56</sup> Thus, at the end of this process—so the orthodox theory argues—an accumulated body of case law would reveal the optimal level of care for any particular market activity, sufficiently litigated, and yield a prescriptive list of minimally required precautions.<sup>57</sup>

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<sup>55</sup> Cooter and Ulen, *Law and Economics*, *supra* note 4, at p. 215.

<sup>56</sup> This is particularly true when a player is far from meeting the optimal level of care. As Grady explains, “...as an injurer takes less precaution, he creates more opportunities for the victim to show a breach of duty. In this sense, the cost-benefit [marginal] approach permits proofs of breach of duty, and the levels of untaken precaution available for the victim’s proof increase as the injurer’s actual precaution decreases.” Grady, *Untaken Precautions*, *supra* note 18, at p. 120.

<sup>57</sup> See generally Guttel, *The (Hidden) Risk of Opportunistic Precautions*, *supra* note 39, at pp. 1398-1400; Cooter and Ulen, *Law and Economics*, *supra* note 4, at p. 215; and Hans-Bernd Schäfer and Andreas Schönenberger, *Strict Liability Versus Negligence*, in 2 *ENCYCLOPEDIA OF LAW AND ECONOMICS* 602 (Boudewijn Bouckaert & Gerrit De Geest eds., 2000).

On the role of precedent in the negligence context, and its relation to limiting the costs of judicial inquiry,



### C. TWO SUGARS OR JUST “SAY WHEN”: THE TWO APPROACHES COMPARED

To illustrate the difference between the two methods, consider the case of *Hendricks v. Peabody Co.*<sup>58</sup> In this seminal case, a sixteen year old boy traveled to the defendant’s abandoned water-filled mine, which was often used for recreational purposes, and was severely injured when he dove into a hidden sand shelf. The court found that the defendant could have taken multiple precautions, such as posting signs, installing a fence, setting up road barricades and employing lifeguards, and eventually affirmed the jury verdict holding the defendant liable for not erecting a “six-foot high steel chain link fence with steel posts set in concrete surrounding the entire pit,”<sup>59</sup> or taking other precautions.

How would the two methods review this case? An aggregated approach would have had to find the socially optimal set of precautions for this fact pattern. In other words, it would have had to perfectly solve the optimization problem at hand, weighing all applicable precautions, behaviors, risks and combinations thereof. For instance, the aggregated approach

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settlements and historical development, see William M. Landes and Richard A. Posner, *Legal Precedent: A Theoretical and Empirical Analysis*, 19 J. L. & ECON. 249, 271-72 (1976) (hereinafter: “*Legal Precedent: A Theoretical and Empirical Analysis*”); Robert D. Cooter, Lewis Kornhauser and David Lane, *Liability Rules, Limited Information, and the Role of Precedent*, 10 BELL J. ECON. 366, 366 (1979) (hereinafter: “*Liability Rules, Limited Information, and the Role of Precedent*”); Claus Ott and Hans-Bernd Schäfer, *Negligence as Untaken Precautions, Limited Information and Efficient Standard Formation in the Civil Liability System*, 17 INT’L. REV. LAW AND ECON. 15 (1997) (discussing negligence adjudication in repeated games); Issacharoff and Witt, *The Inevitability of Aggregate Settlement*, *supra* note 34; and Henry S. Smith, *Modularity and Morality in the Law of Torts*, 4(2) J. OF TORT LAW 1 (2011).

<sup>58</sup> *Supra* note 8. This canonical case is routinely reviewed by leading scholarship in the context of the Hand Formula, particularly in light of its explicit use of numerical values, and is a cornerstone in the teaching of the economic approach of negligence. See, for example, Posner and Landes, *Economic Structure of Tort Law*, *supra* note 3, at pp. 96-97, 102-103; Posner, *Cases and Economic Analysis*, *supra* note 16, at p. 224; Grady, *Discontinuities and Information Burdens*, *supra* note 1; Grady, *A New Positive Economic Theory of Negligence*, *supra* note 28, at p. 131; Stephen Marks, *Discontinuities, Causation, and Grady’s Uncertainty Theorem*, 23 J. LEGAL STUD. 287 (1994) (hereinafter: “*Discontinuities, Causation, and Grady’s Uncertainty Theorem*”) (criticizing Grady’s analysis of and conclusions from the Case from other perspectives); Wright, *Hand, Posner, and the Myth of the “Hand Formula*, *supra* note 17; and Benjamin Lange Meeker, *Is B Less Than Pl? Economic Tort Law Analysis and Our Public Schools: An Opportunity Forgone in Beshears v. Unified School District No. 305*, 31 CREIGHTON L. REV. 1413, 1430-1433 (1998).

<sup>59</sup> *Hendricks v. Peabody Co.*, *ibid*, at p. 39.

could have found that the duty of care in *Hendricks* consisted of posting signs and building an eight-foot steel fence, and conclude that such a combination is socially superior to employing lifeguards or setting up barricades and erecting a seven-foot fence. Once a comprehensive duty of care has been established based on this single judgment, future owners of similar water-filled mines will constructively know exactly how to operate and what to do in order to avoid liability.

In contrast, a marginal adjudication of the *Hendricks* Case need only have found that any of the possible precautions not-taken would have been cost-justified. From the perspective of a marginal approach, it does not matter whether signs were preferable to barricades or whether a six-foot fence was socially superior to an eight-foot one. In order to rule that the duty of care was breached, it is sufficient for the court to find that one of the precautions not-taken pleaded by the plaintiff was marginally cost-efficient at the time of the accident.<sup>60</sup>

This difference raises the question whether the marginal and aggregated approach consistently lead to the same results. More importantly, do the two necessarily arrive at the same *optimal* solutions? Grady considered this “...the most important question that an economic theory of negligence should answer”,<sup>61</sup> and with good reason: ensuring an optimal ruling based solely on a marginal analysis is crucial to establishing its sufficiency to negligence adjudication and superiority over an aggregated analysis.

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<sup>60</sup> A careful reading of *Hendricks* indicates, I believe, that a marginal approach was indeed applied there. See the *Hendricks* Case, *ibid*, at pp. 45-46; and Grady, *Untaken Precautions*, *supra* note 18, at pp. 131-132. The choice between possible precautions not-taken might have implications on causation and harm, which are outside the scope of this dissertation.

<sup>61</sup> Grady, *Discontinuities and Information Burdens*, *supra* note 1, at p. 667.

Unfortunately, as Grady himself demonstrated in a review of Landes and Posner's milestone *THE ECONOMIC STRUCTURE OF TORT LAW*,<sup>62</sup> a marginal analysis might lead to suboptimal results, at least when lumpy variables are at play.<sup>63</sup> Simply put, the fact that an untaken precaution is marginally *cost-effective* does not guarantee in and of itself that it is *optimal*. Merely identifying "the relative positions of the marginal curve"<sup>64</sup> of each precaution, *i.e.* performing a marginal analysis, does not necessarily yield optimal conclusions, however cost-justified.

To illustrate this point, Grady skillfully utilized the *Hendricks* Case, and assigned cost and benefit values to each precaution mentioned by the court. It is worth making a short detour here to review Grady's analysis to this point with some detail, as this dissertation will soon utilize the same framework to demonstrate other shortcomings of the marginal approach, and in fact a fundamental weakness in Grady's own theory.

Grady's cost-benefit values assigned to *Hendricks v. Peabody* are displayed in Table 1. He assumed, as did the court, that the defendant was already using some precautions.<sup>65</sup> The cost of the base precautions level was set at \$10,000, and the overall social cost that resulted, meaning the overall cost of expected harms and precautions, was set at \$60,000. Grady went on to assign values to the remaining four types of possible precautions: lifeguards, fence, barricades and signs. Lifeguards were valued so they would not be incrementally cost-

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<sup>62</sup> Landes and Posner, *The Economic Structure of Tort Law*, *supra* note 3.

<sup>63</sup> Grady, *Discontinuities and Information Burdens*, *supra* note 1.

<sup>64</sup> As Landes and Posner advocate, see Landes and Posner, *The Economic Structure of Tort Law*, *supra* note 3, at p. 87.

<sup>65</sup> The *Hendricks* Case, *supra* note 8, at p. 46 ("[D]efendant undertook to police the area but did not do so effectively"); and at p. 38 ("[T]he only policing of the area was done by defendant's employees on a part-time basis. It was only a part-time activity, and all the employees did, when they found people there, was to take down one or two of the license numbers but nothing further was done about it.").

efficient, evident from the fact that they reduce the expected harm by less than their cost (\$45,000 < \$40,000). The other three precautions were set to be marginally cost-efficient, but of them, only placing warning signs was socially optimal, as it reduced the social costs of accidents to a minimum (\$36,000).

Table 1: Efficient Versus Optimal Precautions in *Hendricks v. Peabody*

<b>Precaution Level</b>	<b>Cost</b>	<b>Risk (PL)</b>	<b>Risk Decrease</b>	<b>Social Cost</b>
<b>Actual</b>	10,000	50,000	--	60,000
<b>Lifeguards</b>	45,000	10,000	40,000	65,000
<b>Fence</b>	14,000	20,000	30,000	44,000
<b>Barricades</b>	10,000	30,000	20,000	50,000
<b>Signs</b>	1,000	25,000	25,000	36,000

Based on the figures detailed in Table 1, the plaintiff in *Hendricks v. Peabody* could have successfully argued that the defendant breached the duty of care by failing to either erect a fence, set up barricades or place signs. Although the court seems to have based its decision, to a large extent, on the defendant’s failure to erect a fence, Table 1 demonstrates that it is entirely possible that another precaution, in this instance signs, was preferable, whereas erecting a fence was simply marginally cost-justified. Similarly, there is no guarantee that the “six-foot high steel chain link fence... set in concrete”<sup>66</sup> discussed by the court was the optimal type of fence, rather than, for instance, a five-foot barbed wire enclosure or a seven-foot wooden wall. The result, as Grady phrased it, is that the mere fact that a certain precaution “might have cost less

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<sup>66</sup> The *Hendricks* Case, *supra* note 8, at p. 38.

than its benefit in the form of reduced risk does not mean that taking it would minimize social cost.”<sup>67</sup>

Grady’s argument on this issue is obviously correct. However, notice that the crux of his reasoning is not that a marginal analysis might lead courts to a wrong conclusion by finding negligence where it does not exist. Rather, it is that courts might find negligence for not the best of reasons. Put differently, a marginal judgment will be correctly decided, though it might rest upon less than perfect reasoning and justification. A foreseeable disadvantage of such judicial decisions is that a behavior prescribed by the court will incentivize future suboptimal (yet marginally efficient) conduct.<sup>68</sup>

Remember though that the marginal approach does not seek to set the overall required investment level or prescribe a conclusive list of mandatory precautions based on a single case. Rather, it only aspires to accurately recognize negligent behavior when it exists. Therefore, Grady’s argument to this point does not “pull the rug” out from under the marginal analysis, nor was it ever intended to do so. It simply points to its limits. In contrast, this dissertation presents common situations in which the marginal approach might fail to achieve even its modest goal of correctly deciding whether or not the defendant was negligent.

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<sup>67</sup> Grady, *Discontinuities and Information Burdens*, *supra* note 1, at p. 671.

<sup>68</sup> Another difference, meaningful in Grady’s analysis, is that the type of precaution not-taken stated by the court would also affect other legal elements required for liability. For instance, damages that would not have been prevented by a particular untaken precaution will fail to meet the causation requirement. Generally, in this dissertation, we assume that causation requirements are met, and do not address the important relationship between pleaded negligent action or omission and causation. On this relationship see, for instance, Saul Levmore, *Probabilistic Recoveries, Restitution and Recurring Wrongs*, 19 J. LEGAL STUD, 691 (1990); Grady, *Discontinuities and Information Burdens*, *supra* note 1; Grady, *Untaken Precautions*, *supra* note 18; and Marks, *Discontinuities, Causation, and Grady's Uncertainty Theorem*, *supra* note 58.

#### **D. TOTAL VALUES AND NEGLIGENCE INQUIRY**

It is perhaps worthwhile to pause at this point, and clarify that neither the marginal nor the aggregated approach call for the Hand Formula to be applied in “total values” or “total terms.” The relevant question in negligence cost-benefit analysis is hardly ever narrowed to whether the total benefit derived from an action or product was higher or lower than the sum of its risks. Such an analysis would, rather obviously, be of limited value. A product can generate a higher benefit than its cost yet be negligently designed, and an activity can be cost-efficient from an overall perspective and still be performed negligently. As Green explains:

“The fact that a kidney dialysis machine is responsible for saving the life of a person with nonfunctioning kidneys is irrelevant to a suit by a dialysis patient against the manufacturer of a machine because it has an electrical defect that caused a serious shock to the patient. The questions of the overall benefit of the kidney machine (or the defendant’s conduct) is irrelevant to the question of whether the costs of a safer design of the machine’s electrical system are less than the costs of electrical shocks to patients who use the machines.”<sup>69</sup>

A “total terms” or “total values” interpretation of the Hand Formula is therefore clearly unjustified, and generally speaking is not applied by the marginal or aggregated approach. The marginal approach focuses on additional cost-justified precautions, and disregards total values. The aggregated approach also does not require negligence inquiry to compare costs and benefits in total terms—it merely calls for the optimal precaution level, or combinations of precautions, to be comprehensively determined. The theoretical debate between the aggregated and marginal approaches, therefore, has little to do with the (erroneous) “total values” interpretation of the Hand Formula, and both approaches would equally reject it.

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<sup>69</sup> Green, *Negligence = Economic Efficiency: Doubt >*, *supra* note 15, at pp. 1612-1615, 1634-1636.

Nevertheless, economic scholarship sometimes advocates the application of the marginal approach by comparing it with the “total values” analysis. For instance, Landes and Posner notes that “courts apply the [Hand] formula in marginal rather than total terms,”<sup>70</sup> and elsewhere that “[t]he relevant cost of accident avoidance is not total cost, but marginal cost.”<sup>71</sup> Similarly, the Reporters’ Note to the Restatement states that “...the negligence standard adopts a marginal approach, recognizing that the relevant issue may be reasonable risk reduction, rather than complete risk elimination.”<sup>72</sup>

The general argument capsulized in these statements is that, (i) since a “total values” analysis or interpretation of the Hand Formula is wrong, (ii) the marginal approach should be followed. This argumentation, however, misstates one of the main dilemmas facing cost-benefit analysis in negligence law. *First*, it ignores the possibility of determining the optimal level of due care in the aggregate, rather than adjudicating negligence through a marginal process. In other words, it creates the false impression that the marginal and “total values” forms of analysis are the only two possibilities to conduct cost-benefit optimization in torts. *Second*, and more importantly, this type of argumentations obscures critical underlying

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<sup>70</sup> Landes and Posner, *The Economic Structure of Tort Law*, *supra* note 3, at p. 102.

<sup>71</sup> Posner, *Cases and Economic Analysis*, *supra* note 16, at p. 2.

<sup>72</sup> RESTATEMENT (THIRD) OF TORTS: PHYS. & EMOT. HARM § 3 (2010), *comment i* and the Reporters’ Note on *comment i*. *Comment i* states “In identifying a precaution that should have been adopted, the party alleging negligence need not prove that the precaution would have eliminated the risk of harm. The party can instead prove that the precaution, if implemented, would have reduced that risk”. The reporters’ Note on *comment i* proceeds to state, however, that “In another sense, however, the negligence standard does not require marginalism.”

A review of the illustrations provided in *comment i* and the corresponding Reporters’ Note make clear that the restatement refers to the marginal approach as defined in the above, rather than simply the opposite of a total values approach. For one, the illustrations provided are entirely predicated upon the underlying assumptions of the marginal approach, further discussed in Part II hereinafter, principally that the efficiency function of taking precautions is continuous and convex. Furthermore, and more telling, the illustration in the Reporters’ Note addresses the unique problems associated with taking suboptimal precautions, and cites to Grady, *A New Positive Economic Theory of Negligence*, *supra* note 28, which described these problems in detail in the context of the precaution not-taken (or marginal) approach as defined above. We can therefore conclude that The RESTATEMENT (THIRD) OF TORTS generally adopts the marginal approach as we defined it, and justifies this choice, in part, by comparing it to the “total values” approach.

assumptions the marginal approach is both predicated and contingent upon, and unduly forces negligence inquiry to operate under highly limited and often misguided assumptions. Parts III and IV address these issues in detail.

#### **E. A HIDDEN TEMPORAL DIVERGENCE**

Scholars have largely overlooked another important distinction, which sets different forms of negligence inquiry apart. Different approaches to negligence cost-benefit analysis often diverge on a temporal or quasi-temporal scale, evident especially in sequential settings. This divergence has to do with the relevant timespan, progression and evidence considered by the courts, as well as the stretch of memory that can be attributed to each form of negligence adjudication.<sup>73</sup>

To illustrate this point, imagine first a lazy art critic who attempts to judge the value of a play by stepping into the theater during the last act. This method might work, at least for plays that build up to a climatic finish where all is revealed. The critic's approach will certainly be less time and energy consuming. However, the critic is also likely to overlook critical elements of most plays, as he or she will miss the development of the plot and characters. In some disquieting cases, the critic will unknowingly misconstrue the entire play, fail to understand the poignancy of an action taken in the final scene, or even mistake the hero for villain. Indeed, Goethe's *Faust* will have a very different meaning for a viewer who is unaware of Faust's pact with Mephistopheles; the tragic ending of Sophocles' *Antigone* will be hard to appreciate if one is ignorant of Creon's initial decree not to bury Polyneices; and Shakespeare's *Hamlet* would

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<sup>73</sup> For a discussion on the temporal aspects in negligence adjudication and the short-run application of the Hand Formula under the marginal approach see, Anderson, *The Missing Theory of Variable Selection*, *supra* note 22, at pp. 270-273.



simply not be the same without witnessing Hamlet's early encounter with the ghost of his father.

The prevailing view among scholars—the marginal approach—risks following the lazy critic's footsteps. It usually applies a highly short-run review, and in its strict version does not require any knowledge or memory of the past. Actions previously taken by the defendant at any point are inconsequential from the perspective of the marginal approach; only whether the defendant could have taken an additional cost-justified precaution is relevant. The marginal approach therefore typically evaluates, adjudicates and lives in the (marginal) moment, or perhaps better phrased, searches for a marginal omission while assuming past actions as given constraints.<sup>74</sup>

The aggregated approach, on the other hand, sometimes operates like an overzealous and tiresome critic, who is unable to ignore pieces of information and meticulously watches plays in full length, weighing all former and recent actions and inactions of all actors. He would view Shakespeare's *Cymbeline* over and over, and refuse to give a review before comparing the play to *Othello* and *The Winter's Tale*, contrasting its latest performance to past adaptations and pondering its influence on the works of T. S. Eliot and Virginia Woolf. In the midst of watching any new play, he would feverishly attempt to speculate all possible developments, picture every conceivable ending and foretell even the most unlikely *deus ex-machina*.

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<sup>74</sup> From a narrow analytical perspective, a precaution not-taken review is not always synonymous to a short-term temporal review. It is theoretically possible for the marginal omission to originate in the far past and for multiple omissions to occur in the present. However, from a realistic and practical perspective, the terms "marginal" and "short-termed" are usually highly correlated. A marginal omission is usually made in the present or near past. That is also where the court is likely to find such omission, should it exist, and where the plaintiff is likely to focus her claims. In real-life, an age-old omission is rarely the marginal omission, and will usually be considered exogenous to negligence cost-benefit analysis.

The aggregated approach, therefore, often delves deeply into the past and far future, considers the full length and breadth of possibilities the defendants had at their disposal, and diligently contemplates former actions and omissions and future possibilities. In its strict version, it applies a cost-benefit analysis that requires full knowledge of alternatives and cumulative possibilities, and necessitates a review of all actions and omissions that arose at any point in the past. As this thesis will soon show, this persistent delving in the past and in first best solutions of the aggregated approach might negate efficient short-run incentives and conceal obvious conclusions from sight. It might also make it difficult for the court to focus on relevant information and allow past impressions to obscure present needs.

The difference between the two approaches is particularly stark in sequential frameworks and when temporal changes occur, best portrayed through another illustration—the 2000 Christopher Nolan movie-classic *Memento*.<sup>75</sup> This film is unique in that it tells a story simultaneously from beginning to end, and in reverse order. From end to beginning, certain deductions and assumptions made by the viewer early on in the film are exposed as problematic or untrue as previous events unfold. From beginning to end, it is easy to become fixated on certain past-events, frame an unsupported narrative and arrive at prejudgment that would not be discarded even as new information to the contrary is revealed or new options become available.<sup>76</sup>

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<sup>75</sup> MEMENTO (Network Films and Team Todd 2000). This film presents a hero with retrograde amnesia and his quest for revenge and justice. The basic storyline is told from two different perspectives: a progression in black-and-white, shown from beginning to end, and a sequence in color, shown in reverse order. The two perspectives “meet” in the middle, reaching the same moment in time at the end of the film. At that point, it becomes apparent that watching the storyline from either flow would leave the viewer with very different impressions, and perhaps even tells a different story. It also becomes evident that the way the story is told, organized and cut into segments inevitably changes the way actions, omissions and events are perceived and judged.

<sup>76</sup> From the hero’s perspective, his amnesia and inability to create a time-progression and new memories makes him vulnerable to manipulation by others. On the other hand, his inability to make judgments based on recent events, and his constant reliving of the past, also lead him to questionable behavior and decisions, and similarly make him

Different approaches to negligence adjudication operate somewhat like the two perspectives in *Memento*. The marginal approach looks only at the last episode of sequential events or omissions, and at most takes a few steps back into the past or attempt to project a splinter into the future.<sup>77</sup> In that, it remembers too little, or suffers from “retrograde amnesia,” and cannot see further than a stone’s throw away. In economic terms, it applies a memoryless and myopic function or algorithm that is easily manipulated by past actions and further-removed options, and assumes all past behaviors as constraints.

In contrast, the aggregated approach can sometimes be said to look at a storyline from beginning to end, in so far as there actually is a “beginning”. In that, it remembers too much and extrapolates too far, and much like an ancient blood feud refuses to forgo the mistakes of the past in order to impose a cost-beneficial solution needed in the present. In more technical terms, it grants inefficient and unwarranted weight to past contingencies, and has difficulty with variable selection, curtailing future hypotheticals and creating short-run efficient incentives. The different inefficiencies resulting from the limitations of both approaches, as well as further hurdles imposed by temporal changes, are reviewed throughout the next parts of this dissertation.

## **F. THE GOLDEN STANDARD OF NEGLIGENCE**

In orthodox scholarship, the debate between the competing approaches to negligence cost-benefit analysis ends with a decisive victory for the marginal approach. So much so, that it would be accurate to refer to the marginal approach as the golden standard of negligence

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susceptible to manipulation.

<sup>77</sup> In continuous frameworks, it might be difficult to decide what timespans and events are “marginal”. We address these issues in detail in Parts III and IV. For a short review of the relationship between past timespans and sequential settings see Anderson, *The Missing Theory of Variable Selection*, *supra* note 22, at p. 270.

adjudication, at least in legal economic literature. “[T]he untaken precaution is the central concept of negligence law”, stated Grady.<sup>78</sup> As Landes and Posner simply put it, the marginal approach is—“correct”.<sup>79</sup>

The marginal approach’s triumph is both normative and descriptive. From a normative perspective, economic scholarship asserts that the marginal approach is superior to setting the level of due care in the abstract, and will produce efficient results at substantially lower costs. From a descriptive standpoint, the scholarship consistently reads Judge Hand’s formulation in *Carroll Towing* as adhering to a marginal view,<sup>80</sup> and similarly appreciates that “the Hand negligence test... is normally performed at a fairly short-run level of analysis”<sup>81</sup> and that “the key question that courts ask is what particular precautions the defendant could have taken but did not.”<sup>82</sup> Grady summarized this claim, noting:

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<sup>78</sup> Grady, *Untaken Precautions*, *supra* note 18, at p. 156.

<sup>79</sup> Landes and Posner, *The Economic Structure of Tort Law*, *supra* note 3, at p. 87 (1987) (discussing a comparison between a marginal and total values interpretation of the Hand Formula). Landes and Posner are clear in stating, “The courts ask, ‘What additional care inputs should the defendant have used to avoid this accident, given his existing level of care?’ The focus on the particular accident and on the particular inputs that could have prevented it invites a marginal analysis.” (*ibid.*). They also abide by the general underlying economic assumptions of the marginal approach, particularly the assumptions of convexity (*ibid.*, at pp. 57-62).

Posner similarly states that: “...to be a correct economic test, the Hand formula must be applied at the margin: the court must examine the incremental benefit in accident avoidance of an incremental expenditure on safety.” (Referring to the conventional economic analysis of negligence in footnote) (Posner, *Cases and Economic Analysis*, *supra* note 16, at p. 3).

<sup>80</sup> See Cooter and Ulen, *Law and Economics*, *supra* note 4, at p. 214 (“[J]udge Hand’s statement of his rule is unclear as to whether the variables refer to marginal values or total values. If we assume that he was a good economist who had marginal values in mind, then we can translate his notion into our notation...”); and Grady, *Untaken Precautions*, *supra* note 18, at p. 145.

<sup>81</sup> Anderson, *The Missing Theory of Variable Selection*, *supra* note 22, at p. 270. See also Richard A. Epstein, CASES AND MATERIALS ON TORTS 154-155 (2000) (“the skillful lawyer typically [pleads his case] by pointing to some specific ‘untaken precaution’ that, if taken, could have prevented the accident that actually occurred.”); Philip G. Peters, Jr., *The Role of the Jury in Modern Malpractice Law*, 87 IOWA L. REV. 909, 948 (2002) (“Plaintiffs typically narrow the scope of the jury’s inquiry by focusing upon an ‘untaken precaution’ and alleging that a reasonable person would have undertaken it. With the task so confined, the jury need not determine the precise combination of safety precautions that would optimize social welfare. Instead, jurors examine the defendant’s failure to take the specific precaution recommended by the plaintiff.”); and Stephen G. Gilles, *United States v. Carroll Towing Co.: The Hand Formula’s Home Port*, TORTS STORIES 11 (Robert L. Rabin and Stephen D. Sugarman eds., 2003).

<sup>82</sup> Grady, *Untaken Precautions*, *supra* note 18, at p. 139.

“Contrary to the [aggregated or Holmesian] theory, courts are not embarked on a quest to make the standard of care ever more clear so that individual conduct can be compared to it. Instead, the courts seem to be pursuing a more modest endeavor: they take the plaintiff’s allegations of the untaken precautions of the defendant and ask, in light of the precautions that had been taken, whether some particular precaution’s promised benefits (in accident reduction) is greater than its associated costs.”<sup>83</sup>

Almost every scholar of the law and economics of torts has embraced a similar view and affirmed the marginal approach as a “good economist[’s]”<sup>84</sup> interpretation of the Hand Formula. Landes and Posner,<sup>85</sup> Cooter and Ulen,<sup>86</sup> Shavell,<sup>87</sup> Grady,<sup>88</sup> Polinsky,<sup>89</sup> Porat,<sup>90</sup> Miceli,<sup>91</sup> Green,<sup>92</sup> Craswell,<sup>93</sup> Harrison and Theeuwes<sup>94</sup> and many others adhere to this

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<sup>83</sup> Grady, *ibid*, at p. 143.

<sup>84</sup> Cooter and Ulen, *Law and Economics*, *supra* note 4, at p. 214.

<sup>85</sup> Posner, *Economic Analysis of Law*, *supra* note 46, at p. 214; Posner, *A Theory of Negligence*, *supra* note 19; Posner, *Cases and Economic Analysis*, *supra* note 16, at p. 3; and William Landes and Richard A. Posner THE ECONOMIC STRUCTURE OF TORT LAW 87 (1987) (claiming that courts need only to identify the relative positions of the marginal curve).

<sup>86</sup> Cooter and Ulen, *Law and Economics*, *supra* note 4, at p. 351.

<sup>87</sup> Shavell, *Economic Analysis of Accident Law*, *supra* note 12, at pp. 32-46 (1987) (discussing different negligence regimes under orthodox economic assumptions), but see pp. 77-79 and 91-93 (applying different considerations in cases of possible prior precautions, as discussed hereinafter, in Part V.G.).

<sup>88</sup> Grady, *Discontinuities and Information Burdens*, *supra* note 1, at pp. 658, 661; and Grady, *Untaken Precautions*, *supra* note 18.

<sup>89</sup> A. Mitchell Polinsky, AN INTRODUCTION TO LAW AND ECONOMICS 43-56 (2003).

<sup>90</sup> Ariel Porat, *The Many Faces of Negligence*, 4 THEORETICAL INQUIRIES L. 105, 144 n1 (2003) (hereinafter: “*The Many Faces of Negligence*”) (“Under the best interpretation, these variables [of the Hand Formula] refer to marginal values. Consequently, the injurer is considered negligent when his marginal costs of precaution fall short of the marginal reduction in the expected damages” (citing to Cooter and Ulen, *Law and Economics*, *supra* note 4)). See also Cooter and Porat, *Does Risk to Oneself Increase the Care Owed to Others?*, *supra* note 24 (applying a highly short-run constrained analysis, viewing past actions and conditions, such as a malfunctioning seatbelt, constraints).

<sup>91</sup> Thomas Miceli, THE ECONOMIC APPROACH TO LAW 26 (2004) (hereinafter: “*The Economic Approach To Law*”) (“If we interpret *B* as the marginal cost of care and *PL* as the marginal reduction in accident costs from that last unit of care, then the injurer will be found negligent under the Hand rule if and only if  $B < PL$ , which is exactly the range over which  $x < x^*$  in the economic model”).

<sup>92</sup> Green, *Negligence = Economic Efficiency: Doubt >*, *supra* note 15, at pp. 1612-1614 (“The burden, or cost of precaution, must be understood as the marginal additional care required to prevent some marginal additional accident avoidance... This means that to employ a risk-benefit test in a tort case, some identified, untaken precaution must exist that, had it been employed by the defendant, would have prevented the plaintiff’s injury.”) Green also notes, however, that the marginal approach may be applied in a wide or narrow manner, that past-taken precautions should be compared with their alternatives and generally seems to prescribe to a wider interpretation of marginal approach than generally

interpretation. Alternative or curbing views are uncommon in contemporary scholarship.<sup>95</sup> The marginal approach has become a fundamental normative attribute of the law of negligence, thought to represent “an old[] conceptual unity” of tort theory,<sup>96</sup> and incorporated into the RESTATEMENT (THIRD) OF TORTS.<sup>97</sup> As the following pages show, this status is not always warranted; certainly not in the unqualified manner it was rendered.

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understood, described and modeled in conventional scholarship. See hereinafter, in Part V.

<sup>93</sup> Richard Crasswell, *Offer, Acceptance, and Efficient Reliance*, 48 STAN. L. REV. 481, 503 (1996) (“rather than trying to assess the entire range of possible precautions... [one should] consider the efficiency of untaken precaution”).

<sup>94</sup> Jeffrey Harrison and Jules Theeuwes, LAW AND ECONOMICS 260 (2008) (“In more technical economic terms introduced earlier, *B* would be the marginal cost of prevention (MCP) and *PL* would be the marginal harm (MH).”)

<sup>95</sup> One contemporary exception is found in Guttel, *The (Hidden) Risk of Opportunistic Precautions*, *supra* note 39. Guttel’s article envisions very different concerns and scenarios than our analysis, and focuses on bilateral precautions. Specifically, he focuses on strategic scenarios between two players, and cases in which “the investment of one litigant strategically affects the ‘burden of precaution’ (*B*) of another litigant” or cases in which “similar strategic behavior... may also involve investments intended to impact the effectiveness of—rather than the cost—of litigants’ possible precautions.” (*ibid.*, at p. 1405). For a discussion of interrelated bilateral precautions see Alan J. Mese, *The Externality of Victim Care*, 68 U. CHI. L. REV. 1201, 1229 (2001) (discussing the innate limitations of the marginal approach in the contexts of joint care settings); Dhammika Dharmapala and Sandra A. Hoffman, *Bilateral Accidents with Intrinsically Interdependent Costs of Precaution*, 34 J. LEGAL STUD. 239, 241 (2005) (discussing certain types of interactions between bilateral precautions); Feldman and Kim, *The Hand Rule and United States v. Carroll Towing Co. Reconsidered*, *supra* note 20, at p. 530; Gary T. Schwartz, *Contributory and Comparative Negligence: A Reappraisal*, 87 YALE L.J. 697 (1978); Mark F. Grady, *Multiple Tortfeasors and the Economy of Prevention*, 19 J. LEGAL STUD. 653, 665 (1990) (hereinafter: “*Multiple Tortfeasors and the Economy of Prevention*”); and Posner, *Economic Analysis of Law*, *supra* note 46, at p. 60 (discussing limitations on a contributory negligence defense in the context of reckless conduct).

<sup>96</sup> Grady, *Untaken Precautions*, *supra* note 18, at p. 156.

<sup>97</sup> RESTATEMENT (THIRD) OF TORTS: PHYS. & EMOT. HARM § 3 (2010), *comment i* and the Reporters’ Note on *comment i*. The reporters’ Note on *comment i* states, “...the negligence standard *adopts a marginal approach*, recognizing that the relevant issue may be reasonable risk reduction, rather than complete risk elimination” and proceeds to state, “in another sense, however, the negligence standard does not require marginalism.” (Emphasis added). *Comment i* states, “In identifying a precaution that should have been adopted, the party alleging negligence need not prove that the precaution would have eliminated the risk of harm. The party can instead prove that the precaution, if implemented, would have reduced that risk”. The illustrations provided in *comment i* and the corresponding Reporters’ Note are entirely predicated upon the underlying assumptions of the marginal approach, namely that the utility functions of taking precautions are continuous and concave. More specifically, the illustration in the Reporters’ Note addresses the unique problems associated with taking suboptimal precautions, and accordingly cites to Grady, *A New Positive Economic Theory of Negligence*, *supra* note 28, which described these problems while endorsing the precaution not-taken approach.

We can therefore conclude that the RESTATEMENT (THIRD) OF TORTS embraces the marginal approach, and as we shall soon explicate does not address to the issues presented in this dissertation. See also in this regard, Cooter and Ulen, *Law and Economics*, *supra* note 4, at p. 215; Gilles, *On Determining Negligence*, *supra* note 15; and Simons, *The Hand Formula in the Draft Restatement Third of Torts*, *supra* note 15.

**PART II:**  
**THE CONVENTIONAL ECONOMIC MODEL OF NEGLIGENCE: FORMAL  
CONSTRUCTION, UNDERLYING ASSUMPTIONS AND LIMITATIONS**

**A. THE PROUD TOWER: THE CONVENTIONAL ECONOMIC MODEL OF NEGLIGENCE**

**a. INTRODUCTION:**

For over thirty years, law and economic theory has constantly strived to perfect a general model of negligence. Rigorously crafted, this model has by now captured the hearts and minds of legal economic scholars, and reshaped the modern understanding and teaching of negligence law. Viewed from the perspective of the 21<sup>st</sup> century, the conventional economic model of negligence is an axiomatic idea; a proud tower<sup>98</sup> of notions, assumptions, views and analyses soaring (nearly) beyond contestation. As Cooter and Ulen state, the law of accidents has been, “successfully analyzed.”<sup>99</sup>

At its core, the rule of negligence requires a plaintiff to prove three elements: (i) breach of duty; (ii) causation; and (iii) harm. Unlike strict liability, negligence law does not limit itself to asking whether the defendant caused a particular harm, but also asks a further question— “[w]as the act blameworthy?”<sup>100</sup> In other words, negligence is centered on the idea of fault, or

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<sup>98</sup> Taken from Edgar Allan Poe, *The City in the Sea* (1831), in COMPLETE STORIES AND POEMS OF EDGAR ALLAN POE 744 (Doubleday, 1966) (“So blend the turrets and shadows there; That all seem pendulous in air; While from a proud tower in the town; Death looks gigantically down.”).

<sup>99</sup> Cooter and Ulen, *Law and Economics*, *supra* note 4, at p. 189.

<sup>100</sup> James Barr Adams, *Law and Morals*, 22 HARV. L. REV. 97, 99 (1908) (“The early law asked simply, ‘Did the defendant do the physical act which damaged the plaintiff?’ The law of today... asks a further question, ‘Was the act blameworthy?’ The ethical standard of reasonable conduct has replaced the unmoral standard of acting at one’s peril”). See also Holmes, *The Common Law*, *supra* note 32, at p. 94-96:

“The general principle of our law is that loss from accident lie where it falls, and this principle is not affected by the fact that a human being is the instrument of misfortune... In the language of the late Chief Justice Nelson of New York: ‘No case or principle can be found, or if found can be maintained, subjecting an individual to liability for an act done without fault on his part... all the cases concede that an

blame, and does not place liability on a defendant who has satisfied the applicable standard of care. Building a systematic model describing the adequate level of care, or reasonableness, is therefore the cornerstone of any economic theory of negligence.

In the next subchapters, we will first review the key elements of the conventional or orthodox model of negligence and its underlying assumptions. We will then revisit our above discussion on the two approaches to negligence adjudication, and using the model, give the two approaches new, concrete and rigorous economic meanings. Lastly, in Parts III and IV, we will relax some of the assumptions the conventional model is predicated upon, and examine the ramifications of doing so on the efficiency of expected outcomes.

#### **b. THE CONVENTIONAL MODEL: A SOCIAL PLANNER'S PERSPECTIVE**

The conventional economic model aims “to optimize... the number [costs] of accidents.”<sup>101</sup> In reviewing this model, we will first derive at the socially optimal level of precaution, as would be chosen a social planner. This outcome will then serve as a benchmark for examining whether different applications of negligence law best “internalize externalities

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injury arising from inevitable accident, or, which in law or reason is the same thing, from an act that ordinary human care and foresight are unable to guard against, is but the misfortune of the sufferer, and lays no foundation for legal responsibility.’ ...

...The undertaking to redistribute losses on the ground that they resulted from the defendants act would... offend[] the sense of justice. Unless my act is of the nature to threaten others, unless under the circumstances a prudent man would have foreseen the possibility of harm, it is no more justifiable to make me indemnify my neighbor against the consequences, than to make me do the same thing if I had fallen upon him in a fit, or to compel me to insure him against lightning.”

<sup>101</sup> Landes and Posner, *The Economic Structure of Tort Law*, *supra* note 3, at p. 13.



created by high transaction costs;<sup>102</sup> or, in other words, ideally incentivize players to reach the social welfare optimum.

The main elements and notations of the orthodox model are as follows:<sup>103</sup>

- (i)  $x$  = The level of precaution taken by the defendant. We assume  $x$  is a continuous variable and that  $x \geq 0$ . We also assume that  $x$  is a single dimensional variable, representing a single continuous precaution (such as the speed of a car or the frequency of safety inspections) or an overall investment level in precaution.<sup>104</sup>
- (ii)  $\omega$  = The marginal cost of precaution, so that  $\omega$  represents the cost per unit of precaution in dollar amounts. For the sake of simplicity, we assume at this point that  $\omega$  is constant and positive.<sup>105</sup>
- (iii)  $p$  = The probability of accidents. We assume  $p = p(x)$  decreases with any increase in precaution, and further assume that  $p(x)$  decreases at a decreasing rate. Thus,  $p(x)$  is a continuous and decreasing convex function of  $x$ ;  $p(x) \geq 0$ ;  $p_x < 0$  and  $p_{xx} > 0$ .
- (iv)  $D$  = The monetary value of harm from accidents, when they occur. We can assume that  $D = D(x)$  is either constant or a decreasing function of  $x$ , in which case we further assume that  $D(x)$  decreases at a decreasing rate. Thus,  $D(x) | (D > 0)$  is a decreasing convex function of  $x$ ;  $D_x < 0$  and  $D_{xx} > 0$  where

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<sup>102</sup> Cooter and Ulen, *Law and Economics*, *supra* note 4, at p. 190.

<sup>103</sup> For a general review see Cooter and Ulen, *Law and Economics*, *supra* note 4, at p. 199-206; Shavell, *Economic Analysis of Accident Law*, *supra* note 12, at pp. 33-36; Landes and Posner, *The Economic Structure of Tort Law*, *supra* note 3; and Miceli, *The Economic Approach To Law*, *supra* note 91, at pp. 15-30. The following model is principally based on these sources.

<sup>104</sup> For the later, the traditional model must also assume that precautions are assigned and chosen based on their relative efficiency, so that the most efficient precautions are selected first; as well as other assumptions. For a discussion on the possibility of and conditions to commensurating precautions, see hereinafter, in Part IV.D.

<sup>105</sup> The analysis would not fundamentally change when  $\omega$  is increasing with  $x$ .

$D$  is positive. For simplicity, we will assume hereinafter that  $D$  is constant for every  $x$ .<sup>106</sup>

We assume players are of two types, injurers and victims, and are strangers to one another. Injurers are all identical, as are all victims, and only victims suffer losses if accidents occur.<sup>107</sup> Parties are all assumed to be risk neutral and rational, and to make decisions based on expected costs and benefits. Social welfare is defined as the sum of the parties' expected utilities, and equivalently, the sum of their goods or assets.<sup>108</sup> We also assume that adjudicators do not err in applying the negligence rule or in assessing damages, that players possess complete knowledge as to expected costs and benefits of their actions and that cost and benefit functions are static and do not change over time. Finally, we assume that precautions are unilateral, meaning that only side (in this case injurers) can affect the risks and expected harms of accidents.<sup>109</sup>

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<sup>106</sup> The analysis does not fundamentally change when  $D$  is constant (meaning accident losses are of fixed severity, conditional on  $D$  being positive) or a decreasing function of  $x$ . Notice that, in the classic model,  $D$  is predetermined, in the sense that if an accident occurs (based on  $p(x)$ ), the corresponding harm is fixed for every  $x$ . It is obviously possible to describe  $D(x)$  as a stochastic function, where the materialized harm is not predetermined for every  $x$ . Notice also that  $p(x)$  and  $D(x)$  are correlated, in the sense that an increase in precaution level ( $x$ ) reduces both the probability of an accident and its expected harm. On that point, and its implication on the first order condition, see also Shavell, *Economic Analysis of Accident Law*, *supra* note 12, at 33 n.49 (“Because  $l(x)$  is expected losses, that is,  $p(x) \int l f(x, l) dl$ , where  $p(x)$  is the probability of an accident and  $f(x, l)$  is the probability density of losses of  $l$  given  $x$  conditional on the occurrence of an accident, the model implicitly allows for accident losses to be of different severity. In the examples of the text losses were of fixed severity”).

<sup>107</sup> For literature relaxing this assumption, resulting in additional insights, see Avon Leong, *Liability Rules When Injurers as Well as Victims Suffer Losses*, 9 INTER. REV. OF L. AND ECON. 105 (1989); and Jennifer Arlen, *Re-examining Liability Rules When Injurers as Well as Victims Suffer Losses*, 10 INTER. REV. OF L. AND ECON. 233 (1990).

<sup>108</sup> Shavell, *Economic Analysis of Accident Law*, *supra* note 12, at p. 33; and Posner, *Cases and Economic Analysis*, *supra* note 16, at p. 3. See also Hal R. Varian INTERMEDIATE MICROECONOMICS – A MODERN APPROACH 57-58, 234-246, and 614-624 (7<sup>th</sup> ed., 2006) (hereinafter: “*Intermediate Microeconomics – A Modern Approach*”) (discussing the definitions of risk neutrality, expected utility and social welfare functions).

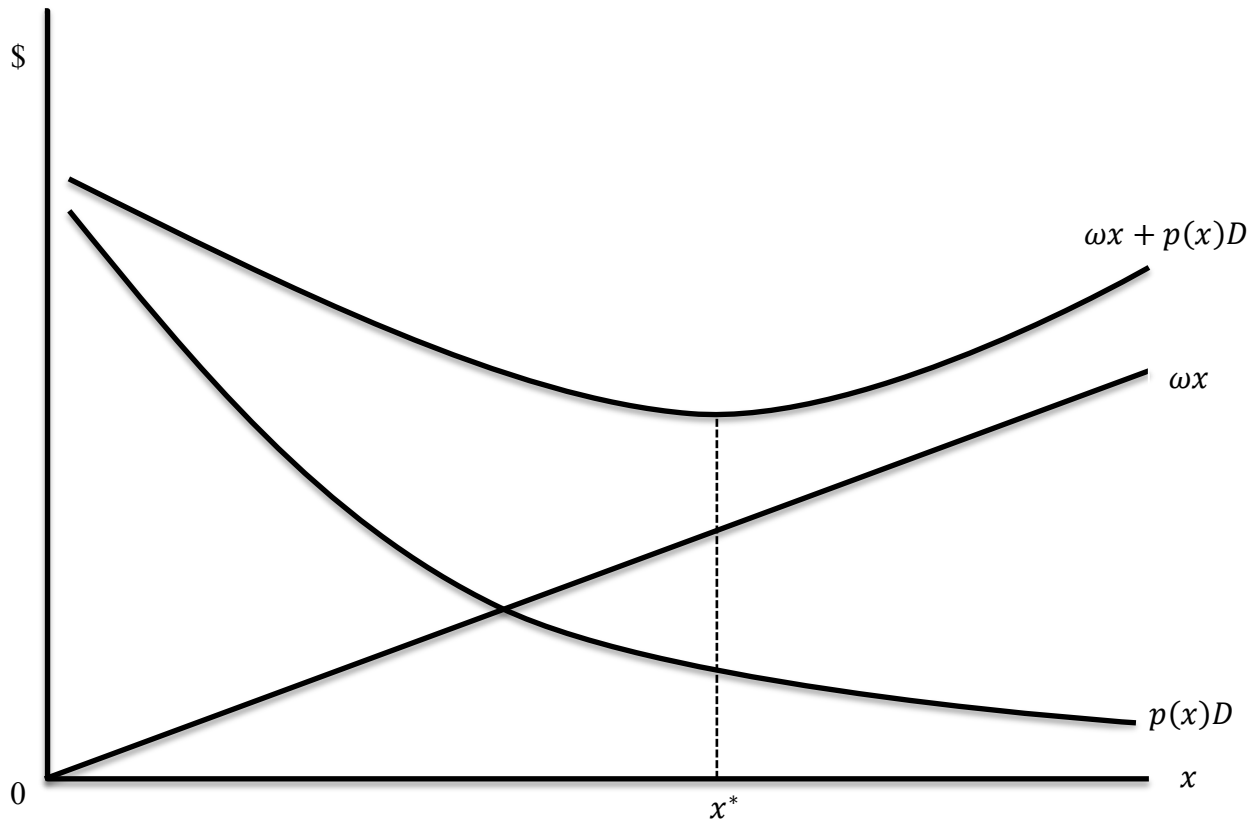
<sup>109</sup> The prolific discussion in economic literature regarding bilateral precautions, in which two or more parties influence the costs of accidents, is generally beyond the scope of the model reviewed in this thesis. As will soon become obvious, while bilateral precautions add an additional layer of complexity to negligence analysis, they do not change the fundamental normative contentions argued here. In fact, I believe that the tendency in tort economic scholarship to focus on strategic bilateral scenarios is one of the main reasons why many limitations of the orthodox model regarding unilateral precaution went unnoticed.

The social costs of accidents are, in the basic model, comprised of only two elements: the costs of harm and the costs of avoiding harm (precaution). The administrative costs of the court system are assumed to be zero or inconsequential. Thus, the expected social cost of accidents ( $SC$ ) can be represented by the formula  $\omega x + p(x)D$ , and the social cost can be minimized by finding  $x$  that satisfies:

$$(1) \quad \min [\omega x + p(x)D]$$

The solution to this problem is best illustrated graphically, as can be seen in Figure II.1. The graph  $\omega x$  represents the total costs of taking precaution, and based on our above assumptions is a straight line through the origin whose slope equals  $\omega$ . The negatively sloped curve  $p(x)D$  represents the expected harm from accidents. The expected social costs can be obtained by vertically adding the line  $\omega x$  and the curve  $p(x)D$  for every level of precaution  $x$ . The result is the U-shaped convex curve,  $\omega x + p(x)D$ .

Figure II.1: The Expected Social Costs of Accidents in the Basic Model



As  $SC = \omega x + p(x)D$  is a U-shaped convex curve, there exists a unique  $x$ -value that would minimize the expected costs of accidents. That value, denoted  $x^*$ , is the socially optimal level of precaution. At all levels of care below  $x^*$ , taking additional precaution will reduce the victim's expected damage by more than its cost, so that the total costs of accidents will be reduced.<sup>110</sup> At all levels of care beyond  $x^*$ , taking additional precaution is assumed to reduce the victim's expected damage by less than the cost of that precaution, so that the total costs of accidents will rise.

<sup>110</sup> For this to be true in multidimensional frameworks, the model must also assume that injurers take optimal precautions for every  $x$ , a point further clarified hereinafter, in Part IV.

$x^*$  can be characterized mathematically, by setting the first derivative of Equation 1 with respect to  $x$  to equal zero. Thus,  $x^*$  is determined by the first order condition:

$$(2) \quad \omega + p_x(x^*)D = 0^{111}$$

So that:

$$(3) \quad \omega = -p_x(x^*)D$$

Equation 3 tells a simple story, according to which  $x^*$  is found where the slope of the  $\omega x$  line equals the (negative) of the slope of the  $p(x)D$  curve. In other words,  $x^*$  is found where the marginal cost of precaution equals the marginal benefit from taking precaution.<sup>112</sup>

## **B. THE TWO APPROACHES TO NEGLIGENCE ADJUDICATION REVISITED**

### **a. GENERAL**

The above discussion established that  $x^*$  represents the socially optimal level of care, and reviewed its key features under conventional assumptions. The next step is to prove that the negligence rule efficiently incentivizes injurers to actually take precaution at  $x^*$ . While this proof is well known in economic literature, the following discussion entails some novelty in separately discussing the two approaches to negligence adjudication: the marginal and aggregated approach. As our analysis demonstrates, both methods efficiently incentivize prospective tortfeasors to invest in precautions, subject to the assumptions of the conventional model.

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<sup>111</sup> Where the first derivative (or first partial derivatives) of  $p(x)$  is  $p_x$ .

<sup>112</sup> Notice that  $x^*$  is not necessarily found at the intersection of the curves in Figure II.1, as they reflect total rather than marginal values.

While discussing the two approaches, we also revisit their principal characteristics, definitions and rationalizations, and give them new, concrete and rigorous economic meanings. As Parts III and IV will demonstrate, these meanings offer new insight into negligence law, and reveal previously unnoticed challenges to negligence adjudication

**b. THE AGGREGATED APPROACH**

**i. THE INJURER'S INCENTIVES**

Negligence is often described as a hybrid between strict liability and no liability regimes; with the point of “due care” as the dividing line between the two regimes. The aggregated approach stems, to a large extent, from this portrayal. Under the aggregated approach, courts are assumed to conclusively set “a definite standard requiring a fixed amount of precaution,”<sup>113</sup> and measure the reasonableness of the defendant’s behavior against it. Put differently, courts are called to conclusively determine the point of due care as a prerequisite to negligence review.

Let  $\tilde{x}$  denote the legal standard of due care set by the court.  $\tilde{x}$  therefore partitions the range of possible precautions into two zones: a permitted (no liability) zone and a forbidden (strict liability) zone. Precautions below  $\tilde{x}$  breach the duty of care, and precautions equal to or exceeding  $\tilde{x}$  satisfy the duty of care. Thus,  $x < \tilde{x}$  implies that the injurer-defendant was at fault, while  $x \geq \tilde{x}$  implies that the injurer-defendant was not at fault.

Based on the above, the injurer’s cost function in the permitted zone will be limited to the costs of precaution ( $\omega x$ ), and will not include the victim’s harm. In the forbidden zone,

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<sup>113</sup> Cooter and Ulen, *Law and Economics*, *supra* note 4, at p. 205 (discussing breach of duty in general).

however, the injurer's cost function will consist of the cost of precaution ( $\omega x$ ) and the expected harm to the victim ( $p(x)D$ ). Thus, we can write the injurer's cost minimization problem under the aggregated approach as follows:

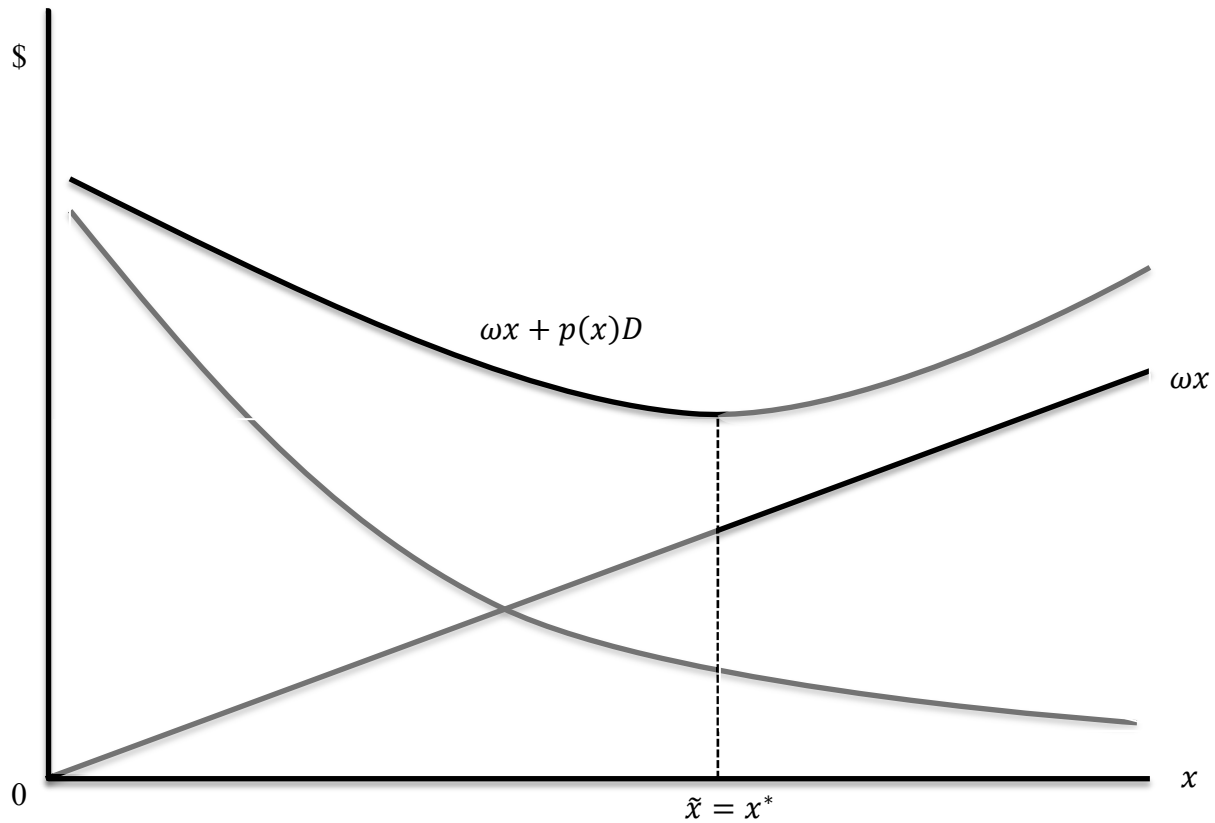
$$\text{Min} \begin{cases} \omega x & \text{if } x \geq \tilde{x} \\ \omega x + p(x)D & \text{if } x < \tilde{x} \end{cases}$$

If courts accurately set the legal standard to equal the socially optimal level of care ( $\tilde{x} = x^*$ ), then  $x^*$  will mark the point of transition between strict and no liability, or between the permitted and forbidden zones. When that is the case, we can alternatively write the injurer's cost minimization problem under the aggregated approach as:

$$\text{Min} \begin{cases} \omega x & \text{if } x \geq x^* \\ \omega x + p(x)D & \text{if } x < x^* \end{cases}$$

Viewed graphically, the injurer's costs in the permitted zone ( $x \geq \tilde{x}$ ) are indicated by the straight-line  $\omega x$  in Figure II.2, while the injurer's costs in the forbidden zone ( $x < \tilde{x}$ ) are indicated by the curve  $\omega x + p(x)D$ .

Figure II.2: The Injurer's Costs Function under the Basic Model



The lowest point, or minimum, in the injurer's cost function (the discontinuous dark line) occurs exactly when the injurer's precaution equals the legal standard ( $x = \tilde{x} = x^*$ ). In the forbidden zone, the injurer's cost function is minimized as  $x$  approaches  $x^*$ . In the permitted zone, the injurer's cost function is also minimized as  $x$  approaches  $x^*$ . Therefore, when the legal standard equals the socially optimal level of care, and perfect compensation is provided to the victim, the negligence rule efficiently incentivizes injurers to take optimal precautions.

To further review the incentive effects of the negligence rule under the aggregated approach, consider how the injurer would set her preferred level of care. It is trivial to



demonstrate that  $x = \tilde{x}$  is a unique Nash equilibrium, where neither injurer nor victim can increase their respective payoffs by taking a different strategy.<sup>114</sup> To see this, assume at first that the injurer sets her precaution level at  $x_1$ , so that  $x_1 < \tilde{x}$ . The injurer's costs in this case would be the costs of precaution ( $\omega x_1$ ) plus her expected liability from accidents  $p(x_1)D$ . Under the model's assumptions, primarily the convexity assumption, taking additional precaution between  $x_1$  and  $\tilde{x}$  would yield a higher return (in reducing expected liability) than its cost. Therefore, a rational injurer will continue taking precaution until she reaches  $\tilde{x}$ , at which point her overall costs would fall to  $\omega \tilde{x}$  ( $\omega \tilde{x} < (\omega x_1 + p(x_1)D) | (x_1 < \tilde{x})$ ).<sup>115</sup>

If, on the other hand, the injurer sets her precaution level at  $x_2$ , so that  $x_2 > \tilde{x}$ , she will be able to increase her payoffs by reducing her precaution level until she reaches  $\tilde{x}$ . To see this, recall that the injurer's cost function above  $\tilde{x}$  consists only of the costs of precautions ( $\omega x$ ), and she is not held liable for the victim's harms. As under our above assumptions the total costs of precautions increases as a function of  $x$ , it must be that  $\omega \tilde{x} < \omega x_2 | (\tilde{x} < x_2)$ . A rational injurer will consequently reduce her precaution level until she reaches  $\tilde{x}$ , and  $x_2$  cannot be an equilibrium precaution level.  $x = \tilde{x}$  is therefore the only solution to the injurer's minimization problem, and a unique equilibrium.

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<sup>114</sup> This is straightforward since, in the basic unilateral precautions model, the victim cannot take alternative actions, and the injurer is the only player who can choose between different strategies.

<sup>115</sup> This is trivial as under our assumptions ( $x > 0$ ), ( $\omega > 0$ ) and ( $(p(x)D > 0)$ ), so that the cost of precaution  $\omega x$  will always be lower than the costs of the same precaution plus the resulting liability for harm ( $\omega x + p(x)D$ ).

## ii. ADDITIONAL ECONOMIC FEATURES

The above discussion also sheds additional light on the methodological process and key characteristics of the aggregated approach. In this regard, it is worth pointing to the following four fundamental features:

*First*, and importantly, the aggregated approach seeks to find the *global optimum* to every tort puzzle. Generally speaking, general optimization is often a more ambitious goal than improving efficiency or performing constrained minimization, and often sets a particularly high set of demands on adjudication. For instance, efficiency and the absence of possible marginal improvements are necessary but insufficient requirements for a global optimum to be established. When, as we shall soon witness, negligence puzzles present with multiple local minima and maxima, and with multiple perfect and imperfect equilibria, the aggregated standard is only satisfied when the defendant's actions—however efficient—corresponded with or exceed the globally optimal set of precautions.

Once the global optimum  $x^*$  is found (or assumed to be found), it becomes the legal benchmark ( $\tilde{x}$ ) against which the defendant's actions are judged. Practically speaking, an “aggregated judgment”, therefore, does not investigate whether the defendant could have taken additional marginally cost-justified precautions or even whether some alternative precaution would have been preferable to a precaution actually taken by the defendant. Rather, the focus of the aggregated approach is simply on whether the defendant has taken or exceeded the prescribed set of precautions constituting due care.

*Second*, the aggregated approach applies an *unconstrained* optimization process, and largely takes an *ex-ante* perspective to negligence analysis. Through an aggregated framework,

every tort optimization puzzle has a particular and predetermined global optimum, which the defendant must meet to the letter (or exceed it). Therefore, the question before a court applying the aggregated approach is not “what is the optimal solution *contingent* on certain past actions taken by the defendant,” but rather “what is the optimal solution conceptually,” irrespective of the defendant’s past actions and sunk costs. As the aggregated approach sets a global optimum for each type of activity in the abstract, the defendant’s past actions or omissions rarely bear weight on the extent of duties and requirements prescribed by the court.

As this thesis will demonstrate, this unique feature of the aggregated approach operates as a double-edged sword. On the one hand, an unconstrained analysis is extremely effective in preventing certain detrimental behaviors by prospective tortfeasors. This is particularly true for attempts by prospective tortfeasors to strategically limit or otherwise influence the available scope of their future precautions. On the other hand, the same unconstrained analysis might lead to inefficient short-run incentives, and generate over-deterrence or under-deterrence when sunk costs are ignored. Parts III and IV will model these effects in detail.

*Third*, the aggregate approach is entirely contingent upon the courts’ ability to accurately and sensibly set the optimal standard of care for each type of behavior. Therefore, it is extremely vulnerable to judicial mistakes in articulating the required level of care ( $\tilde{x}$ ). When the duty of care ( $\tilde{x}$ ) is set at a higher or lower rate than the social optimum ( $x^*$ ), the incentive scheme envisioned by the aggregated approach is distorted, and players might be driven to over or under invest in precaution. Given the overarching prescriptive nature of an aggregated judgment, and its stated goal to regulate widespread behavior, the possible adverse

ramifications of judicial errors in applying the aggregated approach are particularly precarious.<sup>116</sup>

*Lastly*, the aggregated approach does not provide lawmakers with a coherent roadmap to actually set the required level of care, other than generally striving to achieve economic efficiency and the necessary but insufficient notion that  $x^*$  satisfies the (*ex-ante*) first order condition  $\omega = -p_x(x^*)D$ . Amongst the possible sources from which a court may deduce this optimal standard are regulatory acts, social customs, best practices, judicial experience and knowledge, long-term economic and empirical studies, marginal comparisons and case-by-case analyses. In avoiding setting coherent guidelines on how to arrive at  $x^*$ , the aggregated approach arguably solves one problem by creating a larger one in its stead. The innate difficulty in an aggregated analysis is, therefore, what Part I termed “the information problem.” At the end of the day, the processes, evidence, logics and methods courts are to employ in order to arrive at the social optimum remain an unknown mystery under the aggregated approach.

### **c. THE MARGINAL APPROACH**

#### **i. THE INJURER’S INCENTIVES**

As we have just witnessed, the aggregated approach stems from an endeavor to set an overall optimal level of care, and conclusively divide precaution levels to forbidden and permitted zones, with  $\tilde{x}$  representing the “switch point” between them. The marginal approach, on the other hand, is predicated upon the underlying assumptions of the orthodox model. Primarily, it stems from the assumptions that the  $p(x)D$  curve is continuous, strictly

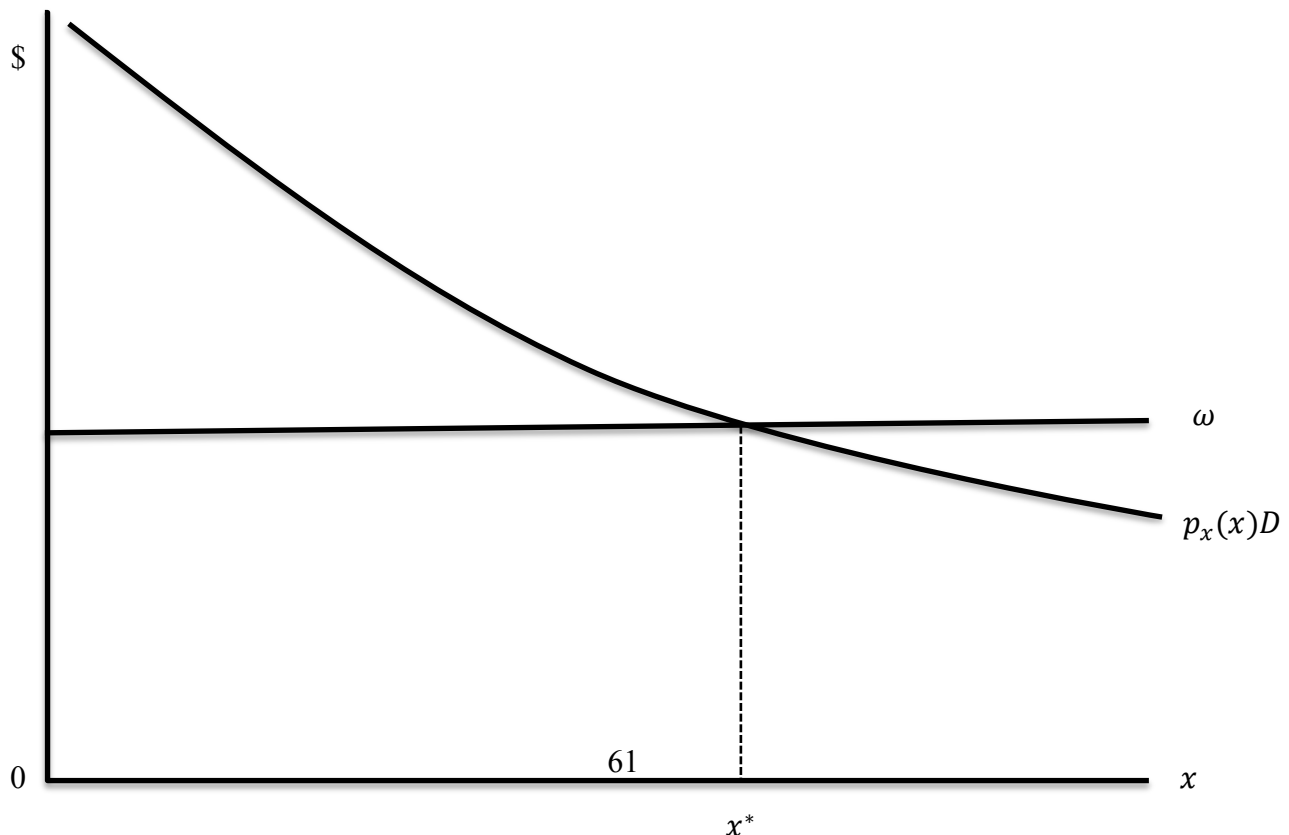
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<sup>116</sup> This is perhaps especially true when market uncertainty as to the judicial standard of care is coupled with player’s risk aversion.

diminishing and convex, and that the marginal cost of precautions ( $\omega$ ) is constant or strictly increasing.

Under these assumptions,  $x^*$  not only marks the social optimal level of care, but also the (single) point of intersection between the marginal cost of precautions and the marginal benefit from reducing accident harm. As Equation 3 demonstrates, the marginal lines of precaution costs and benefits from accident reduction meet only when  $x = x^*$ , where the condition  $\omega = -p_x(x)D$  is satisfied. When the precaution level is lower than the social optimum ( $x < x^*$ ), the marginal cost of additional precaution is lower than the marginal benefit from taking additional precaution. When the precaution level is higher than the social optimum ( $x > x^*$ ), the marginal cost of additional precaution is higher than the marginal benefit from taking additional precaution. Figure II.3 illustrates this point by depicting the marginal costs and benefits of taking precaution under the orthodox model:

Figure II.3: The Injurer's Marginal Costs and Benefit Functions under the Basic Model



The marginal approach utilizes this feature of the orthodox model, in a manner that allows it to avoid the information problem associated with setting  $\tilde{x}$  under the aggregated approach. Under a marginal analysis, courts are not assumed or required to prescribe a global optimal behavior, but rather “compare the relative positions of the marginal curves.”<sup>117</sup> When the marginal cost of taking additional precaution is higher than the marginal benefit from taking such precaution, the injurer-defendant is assumed to be in the permitted zone, and would therefore be found not liable. When the marginal cost of taking additional precaution is lower than the marginal benefit from taking such precaution, the injurer-defendant is assumed to be in the forbidden zone, and would be found liable.

Recall that the injurer’s cost function in the permitted zone is limited to the cost of precaution ( $\omega x$ ), while the injurer’s cost function in the forbidden zone consists of the costs of precaution ( $\omega x$ ) plus the costs of expected harm to the victim ( $p(x)D$ ). Therefore, we can write the injurer’s cost minimization problem under the marginal approach as follows:

$$\text{Min} \begin{cases} \omega x & \text{if } \omega \geq -p_x(x)D \\ \omega x + p(x)D & \text{if } \omega < -p_x(x)D \end{cases}$$

Alternatively, we can describe the injurer’s cost minimization problem using the accumulated social cost U-shaped function,  $\omega x + p(x)D$ . Under conventional assumptions, the social costs function is strictly convex, with a minimum at  $x^*$ . Therefore, when  $x < x^*$ , the social costs function is downward sloping, and when  $x > x^*$  the social costs function is upward sloping. Therefore, for a unilateral precautions model, the injurer’s minimization problem can also be characterized through a marginal perceptible by:

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<sup>117</sup> Landes and Posner, *The Economic Structure of Tort Law*, *supra* note 3, at p. 87.

$$\text{Min} \begin{cases} \omega x & \text{if } \omega + p_x(x)D \geq 0 \\ \omega x + p(x)D & \text{if } \omega + p_x(x)D < 0 \end{cases}$$

As with our above discussion of the aggregated approach, it is trivial to demonstrate that, subject to the underlying assumptions of the conventional model, the marginal approach efficiently incentivizes prospective injurers to take optimal precautions. To see this, assume as before that the injurer takes fewer precautions than optimal, and sets her precaution level at  $x_1$ , so that  $x_1 < x^*$ . As Figure II.3 illustrates, the marginal cost of precaution at  $x_1$  ( $\omega$ ) would necessarily be lower than the marginal benefit in terms of harm reduction at  $x_1$  ( $-p_x(x_1)D$ ). Therefore, an injurer taking  $x_1$  would be found to be in the forbidden zone, and her expected costs would be  $\omega x_1 + p(x_1)D$ . Since the prospective injurer can take additional units of precaution beyond  $x_1$  for a lower cost than the resulting benefit, she will rationally continue taking precautions until she reaches the point where the marginal cost of precautions would equal their marginal benefit ( $\omega = -p_x(x)D$ ). At that point, the injurer's expected liability would fall to  $\omega x$ .<sup>118</sup>

If, on the other hand, the injurer sets her precaution level at  $x_2$ , so that  $x_2 > x^*$ , her marginal cost of precaution ( $\omega$ ) would necessarily be higher than the marginal benefit in terms of harm reduction ( $-p_x(x_2)D$ ). An injurer taking  $x_2$  would therefore be found to be in the permitted zone, where her expected liability ( $\omega x_2$ ) increases with  $x$ . Since the prospective injurer would be able to increase her payoffs by reducing her precaution level so long as  $\omega > -p_x(x)D$ , she will rationally continue reducing her precaution level until she reaches the point where  $\omega = -p_x(x)D$ . Thus,  $x_2$  cannot be an equilibrium precaution level. Only

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<sup>118</sup> It is trivial that  $\omega x < \omega x + p(x)D$  as we have already assumed that  $p(x)D > 0$ .

$\omega = -p_x(x)D$ , or  $x = x^*$ , is therefore the solution to the injurer's minimization problem, and a unique equilibrium in this case.

## ii. ADDITIONAL ECONOMIC FEATURES

The above discussion also sheds a different light on the methodological process and key characteristics of the marginal approach. Specifically, it is worth pointing to the following features:

*First*, unlike the aggregated approach, the marginal approach does not articulate a global minimum to tort puzzles, nor does it state any specific threshold a prospective injurer must meet. Discovering  $x^*$  or ascertaining  $\tilde{x}$  is not part of the marginal framework or mindset. Rather, the marginal approach only endeavors to determine whether the defendant was negligent. It is interested in exploring the desirability of the defendant's untaken actions and adjudicating whether the duty of care was breached, not in stating what that duty entails or where it lies.

The precedential value of a marginal judgment is, therefore, limited. When a defendant is found liable, third parties may only derive that additional precautions were required, but will remain uncertain as to the extent of the additional investment required and the composition of the missing precautions.<sup>119</sup> When a defendant is found not liable, third parties may only derive that fewer precautions might suffice, but again will remain uncertain as to the extent of the permitted reduction in precaution.

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<sup>119</sup> This is particularly true in light of the nature of the adversarial process, and the common law's civil procedure structure of claims, where even if a defendant believes that no additional cost-justified precautions are available, a prospective plaintiff might prove otherwise.



*Second*, the marginal approach studies marginal, rather than total, costs and benefit functions. Practically speaking, the relevant question in conducting a marginal analysis can be framed in one of the following ways: (i) what is the relative position of the marginal curves at the precaution level taken by the defendant?; (ii) what is the slope of the social cost function at the precaution level taken by the defendant?; Or, (iii) could the defendant have taken a single additional cost-justified precaution. In all these forms, the marginal change explored is infinitesimal (for continuous precautions) or minimal (for discontinuous precautions). In other words, the marginal inquiry does not compare different social outcomes resulting from taking non-marginal or wide changes (“jumps”) in precaution levels.

In that regard, it is worth stressing that a marginal comparison is generally less ambitious than global optimization. For one, its scope of inquiry is limited to comparing two marginal cost functions at a particular precaution level, rather than solving an overall minimization problem. This is especially evident, as this thesis will demonstrate, when negligence puzzles present with multiple local maxima and minima, or simply with non strictly convex social cost functions. In such cases, and many others, a marginal inquiry might find a defendant not liable even though she fell short of meeting the optimal set of precautions, or alternatively place liability on a defendant who took precautions exceeding the socially optimal level of care.

*Third*, the marginal approach applies a highly *constrained* optimization process, and largely takes an *ex-post* and myopic (short-sighted) perspective to negligence analysis. Through a marginal standpoint, the defendant must take *additional* precautions for as long as they are *incrementally* cost justified. Therefore, the question before a court applying the marginal approach is not “could the defendant have taken a superior alternative precautions” or

“what would have been the optimal alternative precaution the defendant could have taken in the past.” Instead, the marginal approach merely asks, “could the defendant have taken a single additional cost justified precaution,” beyond those already taken. In other words, the marginal review is “one directional”, and considers past actions and sunk costs as given constraints, while severely limiting the scope of its forward-looking analysis to incremental changes. Alternative precautions, as opposed to additional precautions, fall outside the realm of the conventional marginal approach.

As this thesis demonstrates, this unique feature of the marginal approach also operates as a double-edged sword, with advantages and limitations that mirror the aggregated approach. On the one hand, the constrained marginal analysis is extremely effective in creating efficient short-run incentives, and is able to give adequate weight to and consideration of sunk costs when warranted. This is especially true when a prospective injurer has taken past actions that are not on the optimal set or has overinvested in suboptimal or inefficient precautions. On the other hand, the same constrained analysis might lead to inefficient long-run incentives, and encourage value-destroying strategic behaviors by injurers. This is especially true for attempts by prospective defendant to take actions intended to limit or otherwise alter the scope of their available future precautions. Parts III and IV examine this feature in detail.

*Fourth*, the marginal approach is heavily contingent upon the existence and veracity of the underlying assumptions of the conventional model. Therefore, it is extremely vulnerable to any change in these assumptions. For instance, when the social cost function is not continuous and U-shaped, a given segment may present with a positive slope ( $\omega + p_x(x)D > 0$ ) even though the socially optimal precaution level has not been reached. Similarly, a defendant might invest in precautions to a point characterized by a local minimum in the social costs function,

and mislead a marginal analysis to assume the global optimum has been reached. A marginal analysis therefore might lead to starkly erroneous results, and negate liability for a defendant who has taken fewer than optimal precautions.

*Lastly*, the marginal approach does not provide adjudicators with a solid method to qualify the relative positions of the marginal curves or the expected added value of taking additional precautions. While the focus of the marginal approach on slopes and marginal values limits the severity of the general quantification problem in law and economics, certainty when compared to its aggregated counterpart, measurement difficulties may still hinder attempts to its application. As Judge Posner noted in *U. S. Fidelity & Guaranty Co. v. Plovdba*:

“Though mathematical in form, the Hand formula does not yield mathematically precise results in practice; that would require that B, P, and L all be quantified, which so far as we know has never been done in an actual lawsuit. Nevertheless, the formula is a valuable aid to clear thinking about the factors that are relevant to a judgment of negligence and about the relationship among those factors. It gives federal district courts [...] a useful framework for evaluating proposed jury instructions, for deciding motions for directed verdict and for judgment notwithstanding the verdict, and, in nonjury cases, for preparing Rule 52(a) findings. [...]”<sup>120</sup>

#### **d. INTERIM SUMMARY**

Based on the above, we can summarize the differences between the different approaches in Figure II.4:

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<sup>120</sup> Judge Posner, *U. S. Fidelity & Guaranty Co. v. Plovdba*, 683 F.2d 1022 (7<sup>th</sup> Cir. 1982) (reviewing the reasonableness of boat owner's unloading procedures). See also *McCarty v. Pheasant Run, Inc.*, 826 F.2d 1554, 1557 (7<sup>th</sup> Cir. 1987).

Figure II.4: The Aggregated and Marginal Approaches Compared

	The Aggregated Approach	The Marginal Approach
<b>Goal</b>	Conclusively set a required level of care ( $\tilde{x}$ ) for each type of cases	Determine whether the defendant was negligent in a particular case
<b>Values reviewed</b>	Total values	Marginal (infinitesimal) values
<b>Outcome of ideal review</b>	Global optimum ( $x^*$ )	Relative position of marginal curves at the precaution level taken by the defendant
<b>Precedential value</b>	Significant and general	Limited and specific
<b>Optimization type</b>	Unconstrained	Constrained and myopic
<b>Perspective taken</b>	<i>Ex-ante</i>	<i>Ex-post</i>
<b>Decision benchmark</b>	$x \geq \tilde{x}$	$\omega \geq -p_x(x)D$
<b>Framing of the judicial question</b>	Has the defendant met (or exceeded) the socially required level of care?	(i) What is the relative position of the marginal curves at the precaution level taken by the defendant? Or  (ii) What is the slope of the social cost function at the precaution level taken by the defendant? Or  (iii) Could the defendant have taken an additional cost-justified precaution?

<b>Injurer's minimization problem</b>	$\text{Min} \begin{cases} \omega x & \text{if } x \geq \bar{x} \\ \omega x + p(x)D & \text{if } x < \bar{x} \end{cases}$	$\text{Min} \begin{cases} \omega x & \text{if } \omega \geq -p_x(x)D \\ \omega x + p(x)D & \text{if } \omega < -p_x(x)D \end{cases}$
<b>Main weakness</b>	Limited ability by courts to accurately articulate the socially optimal level of care	Strong contingency upon the underlying assumption of the conventional model
<b>Noted advantage in strategic settings</b>	Efficient long-run incentives Efficient deterrence against attempts by prospective injurers to alter their future scope of available precautions	Efficient short-run incentives Ability to give adequate weight to sunk costs when warranted and incentivizes taking efficient precautions after suboptimal or inefficient precautions were taken.
<b>Noted disadvantage in strategic settings</b>	Inefficient short-run incentives Over or under deterrence resulting from sunk costs and past actions	Inefficient long-run incentives Facilitates and exacerbates attempts by prospective injurers to alter the future scope of their available precautions

A physicist, a chemist and an economist are stranded on a deserted island. After a day of hunger, the three men suddenly come across a can of tomato juice floating ashore. Excited by their unexpected find, they put their heads together on how to open the can:

The physicist says: "I think we can climb the nearest cliff and throw the can down from there. I can estimate exactly the right height from which to drop the can so that it would open upon impact." The other two think for a while... "No! If you miscalculate the distance and release the can from too high up, it will crash on the rocks." The chemist says: "Well, let's light a fire under the can. I can estimate the right temperature and time needed for the can to open just right." The other two think for a while... "No! If you miscalculate and overheat the can, it might explode all over."

The economist grabs his head and laughs: "Guys, you're going about this all wrong... First, assume a can-opener."

## PART III:

### THE ASSUMPTIONS OF THE CONVENTIONAL MODEL RELAXED AND THE FAILINGS OF THE MARGINAL APPROACH: MONOTONE CONVEXITY AND CONTINUITY

#### A. THE BLIND SPOT OF ORTHODOX ECONOMIC THEORY

In Part I, our discussion demonstrated that the marginal approach has been widely accepted as the gold standard of negligence, and is now regarded as the paramount and only coherent interpretation of the Hand Formula. Part II then explored in further depth the underlying assumptions of the conventional economic model of negligence, and described the necessary and sufficient conditions for its (marginal) implementation.

Interestingly, while the marginal approach hinges entirely upon the existence of narrowly tailored prerequisites, legal economic literature has scarcely attempted to relax some of these assumptions. As a result, possible repercussions of applying the marginal approach in myriad scenarios, where conventional assumptions are not met—remain unexamined. As Anderson correctly notes:

“[T]he economic analysis of tort law has been dominated by general models with comparatively little attention to the specific accident-reduction technologies, or the economic structure (the price elasticities and availability of substitutes) of particular recurring accident situations.”<sup>121</sup>

By and large, empirical legal research has also turned a blind eye to the possibility that not all real world settings conform to the assumptions of the traditional model. While torts

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<sup>121</sup> Anderson, *The Missing Theory of Variable Selection*, *supra* note 22, at p. 283 (discussing both normative-analytical and empirical tort scholarship).

scholarship routinely considers questions such as why do people behave recklessly;<sup>122</sup> are particular precautions efficient; was a particular tort reform successful and what effect did case law have on human behavior; it seldom endeavors to empirically explore the true nature of cost functions in distinctive markets.<sup>123</sup> Indeed, Calabresi's call over forty years ago to "test our choices empirically"<sup>124</sup> and examine the real structure of accident costs "as expressed in the market,"<sup>125</sup> was scarcely answered, and often met with practical difficulties. As Calabresi articulates in *THE COSTS OF ACCIDENTS*:

"[T]he general deterrence rough guess must be made with special reference to the relative desirability and uniqueness of activities (as expressed in the market) and to their relation to the costs being allocated.

[...]

Needless to say, all collective judgments as to relative abilities of different activities to achieve primary cost reduction, and as to relative costs at which these could be achieved, are very hard to make and very tenuous."<sup>126</sup>

This somewhat sedulous adherence to orthodox assumptions is, I believe, a critical flaw in our understanding of negligence in torts, and a blind spot in current economic theory. Such rigid perspective is especially perplexing when held against the following reflections: *First*, the

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<sup>122</sup> For a normative discussion see Mark F. Grady, *Why Are People Negligent? Technology, Nondurable Precautions, and the Medical Malpractice Explosion*, 82 NW. U. L. REV. 293 (1988) (hereinafter: "*Why are People Negligent?*").

<sup>123</sup> For examples and exceptions see Don Dewees, *EXPLORING THE DOMAIN OF ACCIDENT LAW: TAKING THE FACTS SERIOUSLY* (1996); Frank J. Chaloupka, *Alcohol-Control Policies and Motor-Vehicle Fatalities*, 22 J. LEGAL STUD. 161, 162 (1993); Elisabeth M. Landes, *Insurance, Liability and Accidents: A Theoretical and Empirical Investigation of the Effect of No-Fault Accidents*, 25 J.L. & ECON. 49, 49 (1982); Benjamin H. Barton, *Tort Reform, Innovation, and Playground Design*, 58 FLA. L. REV. 265 (2006); Michelle Mello and Troyen A. Brennan, *Deterrence of Medical Errors: Theory and Evidence for Malpractice Reform*, 80 TEX. L. REV. 1595, 1597-1598 (2002); and Frank A. Sloan, *Tort Liability Versus Other Approaches for Deterring Careless Driving*, 14 INT'L REV. L. & ECON. 53, 53 (1994).

<sup>124</sup> Calabresi, *The Costs of Accidents*, *supra* note 9, at p. 157.

<sup>125</sup> *Ibid*, at p. 141.

<sup>126</sup> *Ibid, ibid* (discussing the "least cost avoider" concept and general economic principles).



underlying assumptions of the conventional model do not reflect reality in numerous common settings. In fact, the gap between real world settings and the conventional model sometimes lies in plain sight. As we shall demonstrate, life is filled with scenarios that do not conform to orthodox presuppositions, and with tort cases that do not abide by conventional presumptions. From pharmaceutical development to car accidents and from deep water drilling to a bridge faulty construction, torts in action present strikingly different features than those assumed by conventional model.

*Second*, the conventional model is a cornerstone of law and economic theory. It is not an obscure idea that has gone unexplored or concerns a trifling area of law—it is a gem of economic jurisprudential theory, and regarded as “the dominant standard of liability in accident law”.<sup>127</sup> The orthodox model of negligence is a focal point of research and debate, and was the target of exhaustive scrutiny and prolific discussion by legal scholars. Over the years, it has exerted tremendous influence well beyond the confines of tort law, and inspired economic modeling in such areas as criminal, corporate and constitutional law, as well as many other legal fields. The Hand Formula is arguably the most renowned and celebrated economic formalization of a legal term. An overwhelming majority of law students in America, and in other places around the world, study and reflect upon it. Yet, for all its prominence, and the numerous contributions made to the economic understanding of negligence since *United States v. Carroll Towing*,<sup>128</sup> key assumptions of the conventional model remain unquestioned.

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<sup>127</sup> Posner, *Cases and Economic Analysis*, *supra* note 16, at p. 197.

<sup>128</sup> *Supra* note 2.

*Third*, economic theory generally evolves dialectically.<sup>129</sup> Economic frameworks naturally and commonly evolve from within, by relaxing their core suppositions and building upon existing models. In the negligence case, however, the process has not matured. While the conventional model surely grew over time in depth and complexity, multiple presuppositions necessary for its implementation have not been critically and systematically examined. It remains a legal Beetlejuice—say its name and it appears, but few can answer where it comes from or what it stands for.<sup>130</sup>

*Fourth*, and without addressing this issue in depth, certain negligence doctrines and rubrics are best understood and explained as means to meet real world challenges, and bridge the gap between reality and conventional theory. This is the case, I believe, for such doctrines and common law tools as “industry standards” “community standards,” and “best practice”. This element will be further understood after our discussion in Parts III, IV and V.

## **B. THE UNDERLYING ASSUMPTIONS RELAXED AND FUTURE ROADMAP**

The normative lapses surrounding the conventional model need mending. Whether value is served by its limited scope, adhering to the assumptions of the conventional model imposes great social costs. As this thesis illustrates, the reason the marginal approach often fails even in the simplest of settings principally derives from unrealistic, overly simplified and sometimes plainly misguided assumptions and beliefs.

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<sup>129</sup> In the Hegelian *thesis-antithesis-synthesis* sense; see Georg Wilhelm Friedrich Hegel, PHENOMENOLOGY OF SPIRIT (A. V. Miller trans., Oxford, 1977). But compare, in the context of scientific progress, Karl Popper, CONJECTURES AND REFUTATIONS: THE GROWTH OF SCIENTIFIC KNOWLEDGE (New York, 1962); and Karl Popper, THE OPEN SOCIETY AND ITS ENEMIES (Princeton, 1966).

<sup>130</sup> BEETLEJUICE (The Geffen Film Company 1988).

In the following, we will gradually and systematically relax the classic assumptions of the conventional model, and review the theoretical implications of doing so within a unilateral precautions framework. Specifically, we will relax and critically review the following assumptions:<sup>131</sup>

- (i) *Convexity*: The assumption that marginal benefit as a function of taking precaution is downward sloping, *i.e.* that precautions yield a diminishing marginal return;<sup>132</sup> that marginal costs are constant or increasing with precautions; and therefore the curve representing the social costs of accidents is convex and U-shaped;<sup>133</sup>
- (ii) *Monotonicity*: The assumption that marginal costs and benefit functions are monotone, so that in the conventional model the marginal benefit of taking precaution is strictly diminishing and the marginal cost of taking precaution is constant or strictly increasing;
- (iii) *Continuity*: The assumption that precaution measures and their associated cost and benefit functions are continuous;<sup>134</sup>
- (iv) *Single Dimensionality*: The assumption that precautions are one-dimensional, and can be fully and accurately represented along a single axis;

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<sup>131</sup> On some of the standard assumptions of conventional literature regarding negligence law, see Giuseppe Dari-Mattiacci and Francesco Parisi, *THE ECONOMICS OF TORT LAW* (2005), at notes 9-14; and Marks, *Discontinuities, Causation, and Grady's Uncertainty Theorem*, *supra* note 58, and especially at note 2. For a discussion of similar theoretical questions and assumptions, within strategic settings, see Feldman and Kim, *The Hand Rule and United States v. Carrol Towing Co. Reconsidered*, *supra* note 20, at pp. 528-529.

<sup>132</sup> In other words, that the (aggregated) benefit curve of taking precaution is upward sloping and strictly concave.

<sup>133</sup> The shape of the total costs of accident curve is a reflection of our assumptions regarding the cost and benefit functions of taking precautions. For simplicity, we refer to all the above as the convexity assumption.

<sup>134</sup> Orthodox scholarship generally does not explicitly refer to or require costs and benefit functions to be differentiable. However, in most cases, continuously differentiable functions seem to be implied in the analysis.

- (v) *Orthogonality of Multidimensional Precautions, Predeterminacy and Lack of Path-Dependencies*: The assumption that precautions are uncorrelated, and that the scope of possible precautions and their expected marginal efficiency is not path-dependent. This assumption entails that different (or multidimensional) precautions can be ranked, sorted and arranged in perfect order based on predetermined qualities.<sup>135</sup>
- (vi) *Static Systems*: The assumption that cost and benefit functions, as well as the scope of possible precautions, are static and do not change over time or as a result of exogenous intervention.<sup>136</sup>

To these assumptions, we should add two additional implications, which will be further explored throughout this thesis:

- (vii) *Sufficiency and Equivalency of a Short-run Analysis*: The view that a short-run and incremental (or myopic) review is sufficient for optimal results to be reached in all negligence setting, and will produce equivalent results to long-run analysis;
- (viii) *Sufficiency and Equivalency of a Constrained (Memoryless) Analysis*: The view that a highly constrained and *ex-post* (or “memoryless”<sup>137</sup>) review is sufficient

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<sup>135</sup> The orthogonality assumption is relevant to multidimensional frameworks. Interactions between similar precautions, or different levels of similar precautions, will generally be characterized in this thesis using threshold models. The orthogonality assumption is closely associated with the notion that when commensurated to a single axis, precautions are ranked with perfect order, as discussed in Part IV.D., and in Marks, *Discontinuities, Causation, and Grady's Uncertainty Theorem*, *supra* note 58.

<sup>136</sup> The static systems assumption is only generally discussed throughout this thesis. It is perhaps worth while noting here in brief that when temporal changes occur in cost and efficiency functions, evermore disquieting implications can arise out of the application of a strict marginal or aggregated approach. For instance, changes over time in (i) expected risks; (ii) technological opportunities and accident prevention possibilities; (iii) discovery of new information; (iv) costs of precautions; and (v) changes in the net present value (NPV) of future contingencies or their predictability, result in innate tensions within the negligence system, and an impossibility to simultaneously optimize long-run and short-run incentives. This conclusion would become clear upon reviewing Parts III and IV.

for optimal results to be reached in all negligence settings, and will produce equivalent result to unconstrained analysis;

When the above assumptions and implications are not met, the general minimization problem expressed in Equation I, *i.e.*  $\min [\omega x + p(x)D]$ , cannot be solved by a short-run comparison of marginal costs and benefits, and is not synonymous to finding an  $x$  value that satisfies the first order condition of Equations I, meaning that  $\omega + p_x D = 0$ . Put differently, the fundamental criterion of the marginal approach,  $\omega \stackrel{\approx}{=} -p_x(x)D$ , and the mainstream interpretation of the Hand Formula (as articulated also in the RESTATEMENT (THIRD) OF TORTS),<sup>138</sup> are inapplicable when the above assumptions are relaxed.

Parts III and IV are principally dedicated to remodeling the negligence framework and to a critical exploration of the assumptions and conceptions of the orthodox model. They progress as follows:

Part III begins by relaxing the convexity, monotonicity and continuity assumptions. As a main focus, it explores the theory of thresholds and tipping points, and reviews real world examples of their effect in the medical field, such as smoking addiction and epidemic dynamics. The part then continues to discuss the possible consequences of conjointly relaxing these assumptions in two types of cases: (i) local minima appearing before, or antecedent to, the global optimum, and (ii) local minima appearing after, or postliminar to, the global optimum. For each type of case, unique difficulties resulting from the application of the marginal Hand Formula are presented, and possible realistic scenarios and patterns enabling

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<sup>137</sup> By memoryless, we mean that the legal review treats all past actions as sunk, and makes its judgments assuming past-taken actions are given constraints.

<sup>138</sup> *Supra* note 97.

their occurrence are postulated. Part III concludes by reflecting on the fragility and limitations of the conventional model, and its relation to the Anna Karenina Principle, discussed there.

Part IV adds an additional layer of complexity and realism to our analysis, and relaxes the single dimensionality and orthogonality assumptions. In doing so, we introduce the possibility of correlated and multidimensional precautions, systematically categorize possible relationships between them and model the potential adverse effects and challenges to negligence adjudication they present. Specifically, we construct a taxonomy of possible relationships between precautions, and classify them to include: (i) independent (uncorrelated) precautions; (ii) mutually exclusive precautions; and (iii) interacting precautions, which in turn consists of: (a) negatively synergetic precautions; (b) overlapping precautions; and (c) positively synergic precautions. For each type of interaction, assorted suboptimal equilibria, foreseeable strategic behaviors and inefficiencies expected from a misguided application of the marginal approach are uncovered and illustrated. This part ends with further exploring the notion of short-run and constrained optimization.

### **C. THE MONOTONE CONVEXITY ASSUMPTION**

#### **a. THE GENERAL FRAMEWORK AND ITS LIMITATIONS**

The conventional model is founded upon the assumption that the social cost of accidents curve is strictly convex and U-shaped.<sup>139</sup> This assumption implies that: (i) precautions strictly yield a diminishing marginal return for the entire continuum of precautions, so that benefit derived from precaution decreases at a decreasing rate for any level of care, *i.e.*  $\forall (x \geq 0) : p_x D < 0 \wedge p_{xx} D > 0$ ; and that (ii) the marginal cost of precaution is

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<sup>139</sup> See, for instance, Cooter and Ulen, *Law and Economics*, *supra* note 4, at p. 215.

positive and non-diminishing throughout the entire continuum of precautions, *i.e.*  
 $\forall (x \geq 0) : (\omega > 0) \wedge (\omega_x > 0 \vee \omega_x = 0)$ .

As Part II demonstrated, when these presuppositions are met, the social cost of accidents function has a single minimum point, reflecting the optimal level of precaution ( $x^*$ ), or due care. Any investment above this point would be socially excessive, and considered wasteful. Any investment below this point would be socially insufficient, and therefore negligent. Under such conditions, a court can easily adjudicate negligence by examining whether the defendant could have exerted additional cost-justified care, *i.e.* by applying the marginal approach. Cooter and Ulen beautifully personified this presupposition and the judicial process it invites, noting that:

“Just as a climber can reach the peak of a smooth mountain in a fog by always going up, so the court can discover the efficient level of care by holding defendants liable for failing to take cost-justified precautions.”<sup>140</sup>

In reality, however, “always going up” is a bad strategy to navigate through the Himalayan range or the Appalachian trail. It is probably not even a good approach to climb a mountain such as Everest or Kilimanjaro. Most highlands and mountains are not mathematically smooth. They are difficult terrains to traverse, scattered with unexpected elevations and sudden drops. To reach the apex of any highland, or find the safest and most efficient trail to the top of a mountain, a hiker must look more than one step forward. He or she must have a map of the surroundings, plan ahead and consider multiple alternatives and routes.

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<sup>140</sup> Cooter and Ulen, *Law and Economics*, *supra* note 4, at p. 215. Recall, as Part II notes, that sequentially applying the marginal approach is assumed to eventually lead to socially efficient outcomes. Our principal interest here, however, lies in the description of the environment and terrain, *i.e.* the nature of the social costs of accident function.

A misguided climber, applying a myopic “always go up” approach, is more likely to call for a rescue mission than conquer the top of the mountain.

Economic analysis of torts encounters a similar challenge in assorted markets and settings. Reality seldom conforms to, or is best described by, strictly convex accident cost functions. Everyday tort problems, let alone complicated optimization puzzles, often present with multiple local maxima, minima and points of inflection. This is especially true for the oh-so-common stochastic, multidimensional and discontinuous frameworks, where path-dependencies, alternating slope angles and switching costs are also commonly found.<sup>141</sup>

Stated differently, real-world negligence puzzles are rather noisy problems. They occur in complex contexts, frequently lacking an easily obtainable optimal solution. A marginal “always go up” algorithm is certainly unsatisfactory to many of these types of problems. The conventional wisdom encapsulated in Cooter and Ulen’s mountain-climber metaphor fails, therefore, not because it provides bad advice to climb a smooth mountain, but because such a mountain does not exist to begin with.

#### **b. TIPPING POINTS, NETWORKS AND THRESHOLD EFFECTS**

Interactions between two or more precautions best explain why negligence puzzles do not abide by the strict convexity assumption. As argued in Part IV hereinafter, when precautions of different types interact with one another, the resulting social cost function can be highly convoluted, and rarely presents with strictly convex and differentiable features. The

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<sup>141</sup> We discuss multidimensional and discontinuous frameworks hereinafter. For now, it will suffice to note that the difficulties in applying the “always go up” method become even more obvious and detrimental in these settings.



process of solving such puzzles, to expand on Cotter and Ulen's analogy, is similar or analogous to navigating through a treacherous terrain, rather than climbing a smooth mountain.

However, even absent interactions between multiple precautions, there is no reason to think that continuous investments in a single precaution would always, or even predominantly, yield diminishing marginal returns. Many precautions do not present with strictly decreasing marginal benefit functions. In fact, the world is filled with phenomena and behaviors that are best characterized by tipping point or threshold effects. The following chapter is dedicated to these effects.

Thresholds and tipping points are omnipresent. They pervade in the natural world and are a paramount characteristic of social behavior. Water temperature can change with little consequence until it reaches the freezing or boiling points; A medicinal drug can have no therapeutic value until it reaches a certain threshold, and may suddenly become lethal when it exceeds another; Competition in various markets might exhibit a "winner takes it all" effect; A shareholder might be subject to more stringent legal duties once she reaches a certain equity holding; A buyer might enjoy a bulk discount past a certain quantity; A fashion trend may "catch" and expand geometrically once it reaches a certain popularity; A nuclear reaction is contingent on achieving a certain critical mass; and so on.

Countless technologies, products, systems, cost functions and collective human behaviors drastically change once they reach a defined point. From that point, or threshold, things do not build steadily and slowly up or taper off and gently decline. Some systems hit a particular tipping point and then just press the brakes (or gas pedals). Such sudden shifts in

functions and systems that otherwise display gradual or linear progressions may perhaps be counterintuitive and surprising, but are nonetheless common.<sup>142</sup>

The terms tipping point and threshold effects came into common use in the 1970's, in the context of the American housing market and racial divide. As the common narrative goes, white population living in cities in the American Northwest would “flee” to the suburbs when the number of incoming African Americans in a particular neighborhood would reach a certain threshold. At that point, the community would tip, and most remaining whites would leave almost immediately.<sup>143</sup>

Tipping points have numerous examples in everyday life, as well as in negligence-prone settings.<sup>144</sup> To further illustrate the dynamics and commonness of threshold effects, consider the following examples from the medical field:

#### Example 1: Smoking Addiction

Smoking and Nicotine addiction is a complicated phenomenon, with multiple contributing factors. Much like any addiction, it results from and can be explained by various

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<sup>142</sup>For classic descriptions of the tipping point model see Mark Granovetter, *Threshold Models of Collective Behavior*, 83 AM. J. OF SOCIOLOGY 1420 (1978); Mark Granovetter and Roland Soong, *Threshold Models of Diffusion and Collective Behavior*, 9 J. OF MATHEMATICAL SOCIOLOGY 165 (1983); and Thomas Schelling, *MICROMOTIVES AND MACROBEHAVIOR* (1978).

<sup>143</sup> See, for instance, in Malcolm Gladwell, *THE TIPPING POINT* 12 (2000) (hereinafter: “*The Tipping Point*”).

<sup>144</sup> When a new technology is introduced, its assimilation often presents with threshold patterns. This is especially true in the media and communication markets, where network effects cause the utility of goods to increase with the number of users. For instance, fax machines saw a sharp boost in sales past 1987, when they became common and potential users could assume that other potential users also have them. Cell phones followed the same pattern once they crossed a technological threshold of size, price and reception. Crime rates may also change in the same trajectory, with the sudden drop in nationwide crime in the early 1990's (notable in New York) as the prime example. The later example was recently discussed in popular economics literature, see Gladwell, *The Tipping Point*, *ibid.*, at 5-7; and Steven D. Levitt and Stephen J. Dubner, *FREAKONOMICS* 3-6, 114-117 (2005). See also Stephen D. Levitt, *Understanding Why Crime Fell in The 1990's: Four Factors That Explain The Decline and Six That Do Not*, 18 J. ECON. PERS. 163 (2004) and the sources cited there.

physiological, psychological, sociological, environmental and economic means.<sup>145</sup> What is fascinating about Nicotine addiction, however, is that it does not progress in a linear or monotonically convex fashion. People who smoke ten cigarettes a day do not “need” cigarettes ten times as much as people who only smoke one cigarette a day. Light smokers are not lightly addicted, while moderate smokers are moderately addicted and heavy smokers are hard addicts.<sup>146</sup> Rather, there is considerable evidence that addiction or a hard-to-control-need for Nicotine only begins past a certain tipping point, so that light smokers are not addicted at all. Smoking addiction is, in fact, a threshold phenomenon.

Benowitz and Henningfield (1994) estimate that the smoking addiction threshold for daily consumption is located at about the nicotine levels found in five regular cigarettes.<sup>147</sup> What this means is that, for most people, reducing daily smoking from 20 to 18 cigarettes or increasing daily smoking from 2 to 4 cigarettes would have little to no effect on their chances of nicotine addiction or withdrawal symptoms. However, if a person increases his daily cigarette consumption from 4 to 6, her chances of addiction increase dramatically.<sup>148</sup> As they explain:

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<sup>145</sup> Interestingly, smoking also results in varied and correlated harms, such as addiction and increased risk of lung disease and cancer. The various convoluted manners in which these types of harm interacted are also part of the negligence puzzle, and yet an additional reason for the failings of an over simplistic model.

<sup>146</sup> We can define addiction according to the Surgeon General's 1988 Report on Nicotine Addiction: “the compulsive use of a drug that has psychoactivity and that may be associated with tolerance and physical dependence”; see Department of Health and Human Services, Public Health Service. THE HEALTH CONSEQUENCES OF SMOKING: NICOTINE ADDICTION: A REPORT OF THE SURGEON GENERAL. (1988) (DHHS publication no. (CDC) 88-8406).

<sup>147</sup> Neal L. Benowitz and Jack Henningfield, *Establishing a Nicotine Threshold for Addiction*, 331 NEW ENGLAND J. OF MEDICINE 123 (1994) (hereinafter: “*Establishing a Nicotine Threshold for Addiction*”); Jack Henningfield, Neal L. Benowitz and John Slade, REPORT TO THE AMERICAN MEDICAL ASSOCIATION: REDUCING ILLNESS AND DEATH CAUSED BY CIGARETTES BY REDUCING THEIR NICOTINE CONTENT (1997); and Gladwell, *The Tipping Point*, *supra* note 143, at p. 249. See also R. M. Davis, *Moving tobacco control beyond “the tipping point”*, 321 BMJ 309 (2000); and recently Neal L. Benowitz and Jack Henningfield, *Reducing the Nicotine Content to Make Cigarettes Less Addictive*, 22 TOB CONTROL. 14 (2013).

<sup>148</sup> These factual assessments are obviously a matter of expert opinion, which we accept here as true. Benowitz and Henningfield specify that:

“The daily intake of nicotine from tobacco can be estimated from the level of cotinine, the principal metabolite of nicotine, in blood or saliva. The average blood cotinine concentration in addicted smokers is about 300 ng per milliliter. Smokers of 5 or fewer cigarettes per day have average serum cotinine levels of 54 ng per milliliter and an average consumption of 3.9 cigarettes per day. The cotinine level normalized for cigarette consumption is 14 ng per milliliter per cigarette, or 70 ng per milliliter for a person who smokes five cigarettes per day. *Thus, it is reasonable to estimate a level of 50 to 70 ng of cotinine per milliliter as a cutoff point for the addictive threshold...*

...A level of 50 to 70 ng of cotinine per milliliter corresponds to a daily intake of 4 to 6 mg of nicotine. Thus, *5 mg of nicotine per day is proposed as a threshold level that can readily establish and sustain addiction.*”<sup>149</sup>

Indeed, about 10 percent of smokers, sometimes referred to as “chippers”, commonly smoke 5 or fewer cigarettes per day and do not show apparent addiction patterns. They smoke in particular settings and events, may skip smoking for a day or more and can quit with little difficulty and without showing withdrawal symptoms.<sup>150</sup> Their ability to quit at will is a direct result of the nicotine addiction threshold. Similarly, the same threshold puts them at risk of become addicts, should they increase their daily intake of cigarettes by even a small amount.

These and similar findings may have substantial implications in the negligence context. For instance, they might affect the type of claims that should be brought against Tobacco

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“A threshold level for nicotine addiction is a theoretical concept based on observations in current smokers and studies of the bioavailability of nicotine during smoking restriction. That restricting levels of nicotine would prevent addiction needs to be verified empirically.” (Benowitz and Henningfield, *Establishing a Nicotine Threshold for Addiction*, *ibid*).

For our purposes, however, we can assume the contention regarding a 5-cigarette-threshold to be true and exact.

<sup>149</sup> Benowitz and Henningfield, *Establishing a Nicotine Threshold for Addiction*, *ibid* (emphasis added). For more on the effects of cigarettes, Nicotine, Nicotine addiction and policy considerations, see Jeffrey Gray, Neal L. Benowitz, Jack Henningfield et al., *Toward a Comprehensive Long Term Nicotine Policy*, 14 TOB CONTROL 161 (2005); R. D. Hurt and C. R. Robertson, *Prying Open the Door to the Tobacco Industry's Secrets About Nicotine: The Minnesota Tobacco Trial*, 280 JAMA 1173 (1998); J. R. Hughes, A. Blum, N. L. Benowitz and J. Henningfield, *Regulation of the Nicotine Content of Cigarettes*, 331 NEW ENGLAND J. OF MEDICINE 1530 (1994); J. E. Henningfield, E. T. Moolchan and M. Zeller, *Regulatory Strategies to Reduce Tobacco Addiction in Youth* 12 TOB CONTROL 14 (2003); and recently Gray N. Jeffery, *Nicotine Yesterday, Today, and Tomorrow: A Global Review*, NICOTINE TOB RES. (2013).

<sup>150</sup> See Neal L. Benowitz and Jack Henningfield, *Establishing a Nicotine Threshold for Addiction*, *ibid*.

companies, class definitions and boundaries in class actions, adjudication standards applied by courts, FDA regulation policies and so forth. From the perspective of the negligence standard, as we shall soon explore, tipping points may render the marginal approach utterly inapplicable or ineffective, and necessitate a profoundly different optimization scheme.

### Example 2: Epidemics

More often than not, the spread of epidemics can be explicated through threshold models. Some even go as far as to state that, “all epidemics have Tipping Points.”<sup>151</sup> Understanding epidemics is a lesson in the ways in which small changes in continuous variables might have enormous effects. The 1995-1997 Baltimore Syphilis epidemic is perhaps an especially enlightening example.

In 1995, a Syphilis epidemic erupted in Baltimore. As a report by the Baltimore City Health Department (BCHD), the Maryland Department of Health and Mental Hygiene (DHMH) and the Center for Disease Control and Prevention (CDC) indicates, “In 1996 and 1997, Baltimore, Maryland, had the highest rate for primary and secondary syphilis among U.S. cities. From 1993 to 1996, the rate for congenital syphilis (CS) in Baltimore increased from 62 to 282 per 100,000 live-born infants... The increase among blacks was from 113 in 1993 to 564 in 1996.”<sup>152</sup>

This epidemic was distinctive to Baltimore, and occurred despite a dramatic decline in Syphilis incidents across the United States. Nationally, congenital Syphilis rates “declined

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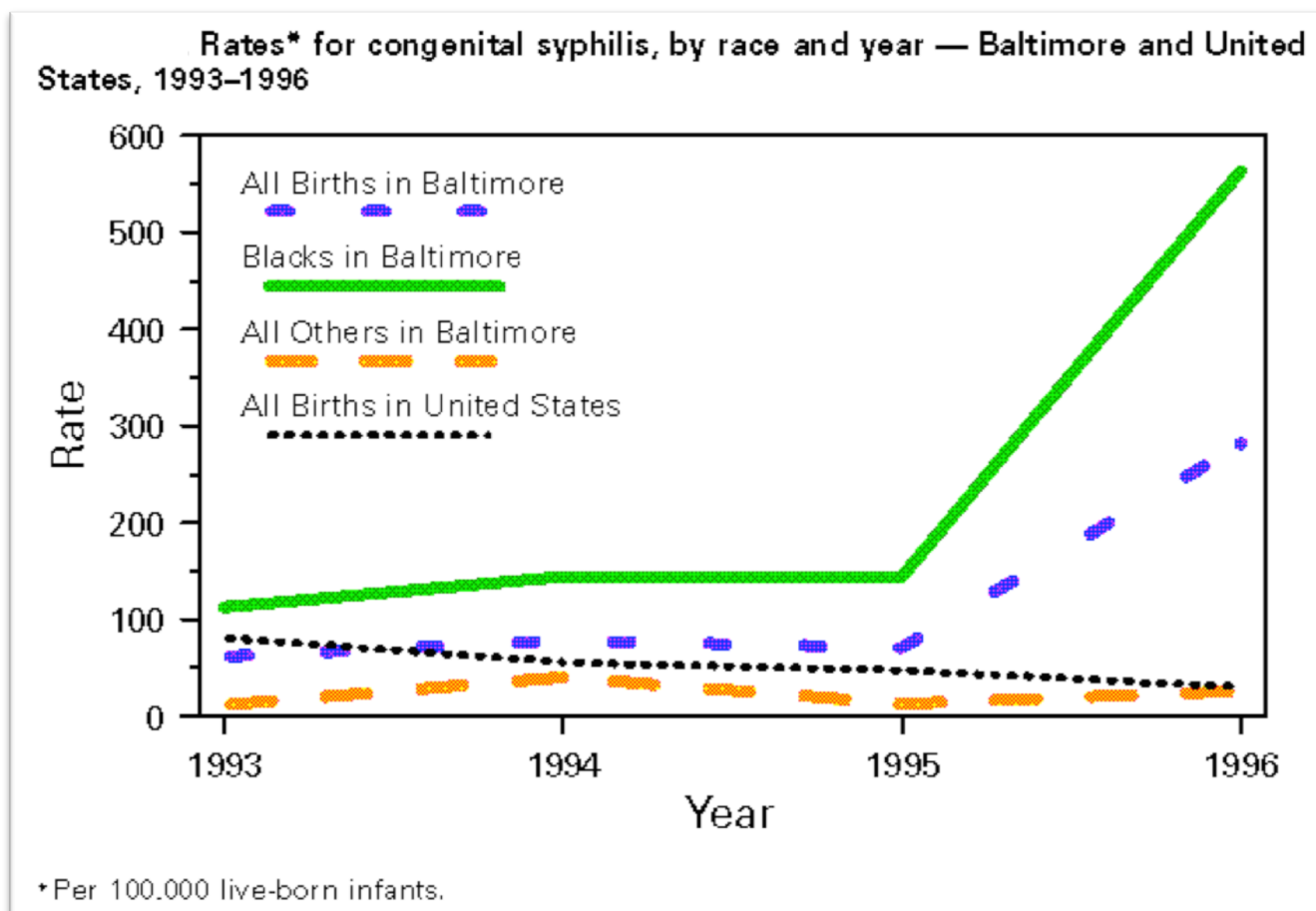
<sup>151</sup> Gladwell, *The Tipping Point*, *supra* note 143, at p. 12. For a short criticism, see Andrew Schultz, *Book Review: The Tipping Point: How Little Things Can Make a Big Difference*, 38(4) JOURNAL OF INDUSTRIAL TEACHER EDUCATION (2001).

<sup>152</sup> CDC, *Epidemic of Congenital Syphilis -- Baltimore, 1996-1997*, 47(42) MORBIDITY AND MORTALITY WEEKLY REPORT 904 (1998) in URL: <http://www.cdc.gov/mmwr/preview/mmwrhtml/00055498.htm> (hereinafter: “*Epidemic of Congenital Syphilis -- Baltimore, 1996-1997*”).

72% from a peak of 107 cases per 100,000 live-born infants in 1991 to 30 in 1996; in Baltimore, the rate was nearly 10-fold higher in 1996 than the national rate. Among blacks, the national rate was 128 per 100,000 live-born infants in 1996 compared with 564 in Baltimore.”<sup>153</sup>

But this particular Syphilis epidemic was more than just distinctive on a national scale. What is crucial for our purpose here is that Baltimore did not see a gradual increase in Syphilis rates over the span of a few years. Rather, it was overwhelmed by the spread of the disease in a short timespan. While Syphilis rates in Baltimore hardly changed between 1993 and 1995, and even subsided during some of these years, Baltimore Syphilis rates suddenly “tipped” or spiked in 1995. Chart III.1, prepared by the BCHD, BMMH and CDC, displays the rates of Syphilis by race and year in Baltimore, compared with the national rates:

Figure III.1: Syphilis Rates in Baltimore Between 1993 and 1996<sup>154</sup>



The facts unambiguously show that 1995 was the tipping point of Syphilis rates for the Baltimore population in general, and for its African Americans community in particular. Various explanations have been suggested for this Syphilis eruption. For instance, the outbreak was linked to changes in the operation of Baltimore's public health system; increase consumption of Crack-Cocaine amongst the resident population; and housing dislocations affecting sociosexual networks.<sup>155</sup>

It is highly probable that the actual reason for the Baltimore epidemic was comprised of multiple factors. As with many real world events, the end result can likely be traced back to a number of root causes working with cumulative synergism. At this point, however, let us assume that Syphilis rates in Baltimore responded to a single variable only, and limit ourselves to reviewing one of its possible explanations. In other words, let us operate under the orthodox assumption of single-dimensionality, and postpone our discussion of multivariable interacting precautions to Part IV.

Perhaps the most compelling single explanation for the Baltimore Syphilis epidemic links the outbreak to cutbacks in public health services provided to Baltimore residents, and the consequent breakdown of medical services in the city's poorest neighborhoods. As Zenilam, an expert on sexually transmitted diseases of John Hopkins University in Baltimore, explains:

“In 1990-91, we had thirty-six thousand patients visits at the city's sexually transmitted diseases clinics... Then the city decided to *gradually* cut back because of budgetary problems. The number of clinicians went from seventeen to ten... patient visits dropped to

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<sup>155</sup> See Gladwell, *The Tipping Point*, *supra* note 143, at pp. 15-19, 27. See also CDC, *Outbreak of Primary and Secondary Syphilis -- Baltimore City, Maryland, 1995*, 45(08) MORBIDITY AND MORTALITY WEEKLY REPORT 166 (1996) in URL: <http://www.cdc.gov/mmwr/preview/mmwrhtml/00040527.htm>.

twenty-one thousand... It was the worst-case scenario of city bureaucracy not functioning...<sup>156</sup>

The explanation suggested by Zenilman attributes the Syphilis epidemic to a gradual dilution of STD clinics in Baltimore, and to the corresponding reduction in yearly patient visits to these clinics. In 1990, the number of yearly patient visits to Baltimore's STD clinics was 36,000. This number was then *gradually* cut back from 36,000 to 21,000 over the span of five years. Assume, for simplicity, that the number of visits in 1991 was about 33,000, the number of visits in 1992 was about 30,000, the number of visits in 1993 was about 27,000, the number of visits in 1994 was about 24,000 and the number of visits in 1995 was 21,000.

As Figure III.1 illustrates, the gradual reduction in patient services between 1990 and 1995 was not correlated with an increase in Syphilis rates. In fact, the disease seems to have been kept at bay when the number of yearly visits was cut from 36,000 to 33,000, and from that point to 30,000 and again to 27,000 and 24,000. According to Zenilman, only when the number of yearly visits hit about 21,000, did the city experience a sudden and dramatic Syphilis epidemic. That would imply that 21,000 yearly patient visits was the Syphilis threshold in 1995 Baltimore.<sup>157</sup>

The Baltimore Syphilis epidemic, as a product of reduced levels of public health services, cannot be explained by the rule of diminishing marginal returns. The data suggests that the marginal harm from Syphilis as a function of changes in the number of yearly patient visits above 21,000 was close to zero. The "final straw" in 1995, however, had tremendous

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<sup>156</sup> As quoted by Gladwell, *The Tipping Point*, *ibid*, at pp. 15-16 (emphasis added).

<sup>157</sup> We assume, for simplicity, a deterministic and single-dimensional model, with equivalent conditions over different years. Naturally the actual events can be modeled using stochastic and multidimensional frameworks. Note also that, based on this data, it could be that the cutoff point was somewhat higher than 21,000, for instance as a result of a lagging effect (where the results of past cutbacks in medical care only manifest at a later time).



significance. At that point, the average frequency of clinic visits and treatments could not keep up with the rate of infection, and the number of patients began to exponentially spiral out of control.

**c. INTERIM SUMMARY AND ALTERNATIVE METAPHOR**

Our object here was not to study epidemics, addiction patterns or consumer choices in the pharmaceutical market. The above examples were brought for the limited purpose of demonstrating that thresholds effects are prevailing elements of the natural and social world, and that myriad settings present with convoluted non-orthodox social costs functions. The normative implications of these finding are further illustrated and discussed hereinafter. However, two short conclusions can be derived from the above discussion at this point:

*First*, courts and policy makers cannot blindly assume that all torts scenarios fully abide by the rule of diminishing marginal returns and the other suppositions of the conventional model. Applying the marginal approach without first verifying the true nature of the relevant cost and benefit functions would be imprudent and ill-advised. In that respect, the importance of studying actual cost and benefit functions in the real world cannot be overstated.

*Second*, the “smooth mountain” metaphor is, rather obviously, unfitting for threshold and epidemic settings. That representation is only applicable to the limited circumstances where all of the assumptions of the conventional assumptions are met. A more persuasive metaphor for the progression, dynamics and phenomenology of epidemics and tipping points is that of a water dam built out of sandbags.

A dam must be higher than the height of incoming water if it is to prevent floods. More importantly, if water pressure rises above a certain point, a makeshift dam of sandbags would break and collapse. The effectiveness of a dam therefore tips at a particular pressure point. Assume for simplicity that the threshold point is always found when the water is at height of the dam.<sup>158</sup> Thus, if the dam is higher than the water level, adding sandbags or taking them away would have no effect on the final outcome. Conversely, while the a dam is lower than the expected water level, changes in the number of sandbags would also bare no consequence on the final outcome. At the water level, however, small alterations in the height of the dam can make all the difference between catastrophic or miraculous consequences.

In reality, there are far more dams and unforeseen highlands than smooth mountains.

#### **D. THE CONTINUITY ASSUMPTION**

The conventional model is predicated upon the assumption that precautions are strictly continuous, and generally ignores lumpy settings and outcomes. While this dissertation discusses ample discontinuous variables and functions, and predominantly deliberates lumpy settings, orthodox economic scholarship “prefer[s] to develop theory using continuous variables.”<sup>159</sup> The RESTATEMENT (THIRD) OF TORTS follows the same path in the sections dedicated to breach of duty, and provides illustrations principally characterized by continuous variables.<sup>160</sup>

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<sup>158</sup> In reality, things are naturally more complicated, and are contingent on several correlated factors. An analysis of such multidimensional frameworks is set in Part IV hereinafter.

<sup>159</sup> Cooter and Ulen, *Law and Economics*, *supra* note 4, at p. 196.

<sup>160</sup> RESTATEMENT (THIRD) OF TORTS: PHYS. & EMOT. HARM § 3 (2010), in *Comment f, Illustration 1* (addressing the height of uninsulated electric wire) and *Illustration 2* (addressing inspection programs for tree hazards; where the time interval between inspections can be conceived as a continuous variable, while a choice between different annual inspection schemes can be described as discontinuous).

This focus of orthodox economic scholarship on continuous settings is no coincidence. Continuity is an essential element of the conventional model, instigated by the idea that continuous models are more elegant, instructive and “clean”. As Cooter and Ulen explain:

“In general, discontinuous variables and cost functions yield messy results about optima, whereas continuous variables and cost functions yield clean results. It is usually best to build theory from clean results and then handle any messy results as exceptions.”<sup>161</sup>

Cooter and Ulen have it backwards—discontinuities are the norm, not the exception. What is true is that discontinuities may present distinct challenges. For instance, as we have already noted in Part I when discussing *Hendricks v. Peabody*, applying the marginal approach when lumpy variables are at play might result in suboptimal (yet *ex-post* efficient) judgments.<sup>162</sup> In such cases, a court might correctly find the defendant negligent, but do so based on a failure to take an efficient (yet suboptimal, *i.e.* not first best) precaution rather than a failure to take the optimal precaution. With that said, I claim the orthodox rigid assumption of continuity is misguided. The reasons for that are descriptive, practical and theoretical:

From a descriptive perspective, the conventional model ignores the remarkable prevalence of discontinuities. It does not give adequate weight, or any weight for that matter, to the fact that many if not most tort puzzles are predominantly represented by discontinuous variables and cost functions. This is especially true from a short-run perspective, generally said to apply in negligence law.<sup>163</sup> As Miceli notes, “[o]ne complication in applying the marginal

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<sup>161</sup> Cooter and Ulen, *Law and Economics*, *supra* note 4, at p. 210; but see Bayern, *The Limits of Formal Economics in Tort Law: The Puzzle of Negligence*, *supra* note 21, at pp. 738-740 (discussing possible advantages of exceptional desecrate precautions in bilateral-precaution settings).

<sup>162</sup> See Grady, *Discontinuities and Information Burdens*, *supra* note 1.

<sup>163</sup> See Mark F. Grady, *Response, Another Theory of Insufficient Activity Levels*, 108 MICH. L. REV. 30, 31 (2009) (hereinafter: “*Response, Another Theory of Insufficient Activity Levels*”) (discussing lumpy and differential variables and noting, “Fixed-cost assets are only fixed in the short run, not because they are inherently lumpy, but

analysis to actual accident cases is that care usually does not vary continuously but comes in discrete bundles.”<sup>164</sup> From seatbelts to warning signs and ultrasound tests, and from airbags to scaffoldings and plasmapheresis, the world we live in is pieced together with discontinuous causes and outcomes.

Discontinuous variables and functions may very well lead to “messy” results, as Cooter and Ulen maintain, but that does not make them any less pivotal, widespread and worthy of attention. A general theory of negligence that fails to address discrete variables and functions will not only poorly reflect reality, but also fall far short of offering sensible solutions to real world problems. Formal tort models, therefore, must not view discontinuities as minor and rare exceptions. They should regard them as generally prevalent.

From a practical perspective, continuous and discontinuous definitions are often interchangeable, and may result from alternative classifications rather than substantial differences. For instance, a rearview mirror can be framed as a binary precaution (“was a rearview mirror used or installed?”), a lumpy precaution (“the number of glances at the rearview mirror made by the driver”), or a continuous precaution (“average frequency of looking at the rearview mirror” or “average time length of looking at the rearview mirror”).<sup>165</sup> Health inspection at a local restaurant, to use another example, can be described as a binary, lumpy, or continuous precaution in much the same way (“were health inspections performed?” “the number of health inspections performed over the last year,” and “the average frequency of

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because the entrepreneur has irrevocably invested in a factory (or other durable asset) of a particular quality and quantity... Economists usually deny that nondifferentiable costs and assets exist. If lumpy resources were common, production theory would be totally different.”)

<sup>164</sup> Miceli, *The Economic Approach To Law*, *supra* note 91, at p. 26.

<sup>165</sup> For a similar claim regarding the distinction between activity levels and care measures see Dari-Mattiacci, *On the Optimal Scope of Negligence*, *supra* note 22, at pp. 335-7.

health inspection”). Most precautions can be interchangeably defined as continuous or discontinuous, and rearticulated in alternative forms.

Furthermore, continuous precautions can and often do manifest in lumpy quantities or bundles, yet again blurring the distinction between the two terms. Nicotine levels are perhaps continuous in nature, but nicotine consumption is usually made through cigarettes (or Nicotine patches), which are generally thought of as discrete.<sup>166</sup> The height of a wall is usually conceived as a continuous precaution, yet that may have little bearing if the wall can only be built using bricks of a set size. Practically speaking, continuous variables and functions frequently present in discrete inputs.

In a way, the conventional model can be said to envision a hypothetical state of nature or *ex-ante* world, where the realm of possible precautions is limitless and continuous. In other words, the conventional model is entrenched in the “primal” state of the world, where the theoretical broad spectrum of continuous precaution has not yet been “chopped” into discrete (and concrete) bundles or units, and where investments are not already sunk. In that sense, the conventional model’s continuity assumptions can be viewed as the application of *ex-ante* wisdom onto an *ex-post* world. While precautions can indeed come in limitless and arbitrary sizes and shapes in an abstract world<sup>167</sup>—they usually must take some particular discrete form in the real one.

Finally, from a theoretical perspective, the orthodox view is misguided in supposing that continuous precautions always, or even commonly, yield “clean” results, as Cooter and

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<sup>166</sup> Cigarettes can also be construed in continuous terms, for instance by measuring the length of the cigarette smoked. This is yet another exemplification of the interchangeability principle.

<sup>167</sup> In much the same way as a Meter, Feet or Yard are “arbitrary” units that describe a continuous variable (distance).

Ulen claim. Many times, that is not the case. Continuous variables can have discontinuous costs and benefit outcomes, and as we have already demonstrated are sometimes best characterized by threshold models. In the presence of thresholds, not to mention non-monotone functions, the task of optimizing overall social costs can be as challenging, difficult and treacherous for continuous variables as it is for discontinuous variables.

Moreover, even when a continuous precaution manifests in continuous and strictly convex outcomes when taken alone, it may interact with other variables (in multidimensional frameworks), and result in lumpy or non-monotone outcome functions for that reason.<sup>168</sup> When such interactions occur, the results are likely to be unpredictable and highly convoluted.

To summarize our discussion at this point, continuous precautions do not and cannot guarantee simple, elegant or “clean” results, and much like any negligence variable necessitate a case-by-case (or market-oriented) analysis coupled with a tailored optimization processes. To illustrate just a few common complications prevalent to continuous precautions, consider the example of a hypothetical medical drug, consisting of the active ingredient, say QRS.

*First*, while QRS can theoretically be taken in continuous amounts, it is possible that it is only available in lumpy quantities. This is the case, for instance, when QRS is marketed in pills of a set dose. When QRS is only obtainable in discontinuous quantities, the theoretical continuous nature of its input and output functions would make little difference, and any realistic model for its use will have to take discontinuities into account.

*Second*, the continuous nature of QRS does not assure that its effect on the human body will be continuous and positively or negatively monotone. For example, the beneficial results

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<sup>168</sup> As discussed in Part IV hereinafter, while it may be that discontinuous outcomes (in the strict mathematical sense) are—under some conventional assumptions—atypical or not possible in a plain of two continuous variables, non-monotone outcome functions are, in fact, highly likely in such settings.

of administering QRS might only appear within a certain range. Before a particular threshold is reached, QRS might have no effect on the human body. Past another threshold, QRS might suddenly become toxic or harmful. As a result, administering QRS in continuous levels can have discontinuous and non-strictly convex outcomes.

*Third*, even if QRS abides by the rule of diminishing marginal returns when taken alone, it might interact with other drugs. Such interactions can (and often do) alter the expected outcome in intricate manners. Once QRS interacts with other substances, the aggregated result might display with fluctuating marginal benefits, be best characterized by threshold models, and under specific conditions even present with discontinuous outcome functions. In all these cases, and many more, the marginal approach is inapplicable and likely inefficient.

#### **E. ILLUSTRATIONS AND NORMATIVE CHALLENGES**

So far, we began demonstrating that the conventional model is predicated upon overly simplified and sometimes plainly misguided assumptions, and examined the monotone convexity and continuity assumptions. In the following pages, we will review the normative implications of applying the marginal approach to setting where these two assumptions are not met.

As will soon become clearer, once the fragile assumptions of the conventional model are destabilized, the resulting costs and benefits functions might be extremely diverse and hard to predict. Loosely phrased, “anything can happen” once the convexity and continuity assumptions are relaxed. The following is therefore a limited illustration of possible models and conceptual difficulties that arise in realistic settings, rather than a comprehensive analysis of all possible outcomes and models.

**a. CASE STUDY A: LOCAL MINIMA ANTECEDING THE GLOBAL OPTIMUM**

**i. EXAMPLE AND ILLUSTRATION**

We begin by discussing a classic threshold model, where the marginal benefit from taking a single precaution is downward-sloping and upward-sloping interchangeably. In this example, we will assume that both the precaution and the benefit resulting from taking it are continuous.<sup>169</sup> As before, the marginal cost of precaution ( $\omega$ ) is assumed to be continuous, positive and constant.

To make things more concrete, consider a case of a pharmaceutical drug, *XYZ*. This drug presents with two thresholds: it is extremely beneficial only after a particular dose is reached (range of Threshold *a*), and becomes toxic past another threshold (range of Threshold *b*). Thus, the marginal benefit from administering *XYZ* is positive and increasing at the range of Threshold *a*, and the benefit from administering *XYZ* is negative past the range of Threshold *b*.

Figure III.2 roughly illustrates the marginal cost and benefit functions of administering *XYZ* (in blue and black) juxtaposed to the marginal benefit function of a drug the abides by the assumptions of the conventional model (in grey);

Figure III.3 roughly illustrates the total benefit function of administering *XYZ* (in blue) juxtaposed to the total benefit function of a drug that follows the assumptions of the conventional model (in grey);

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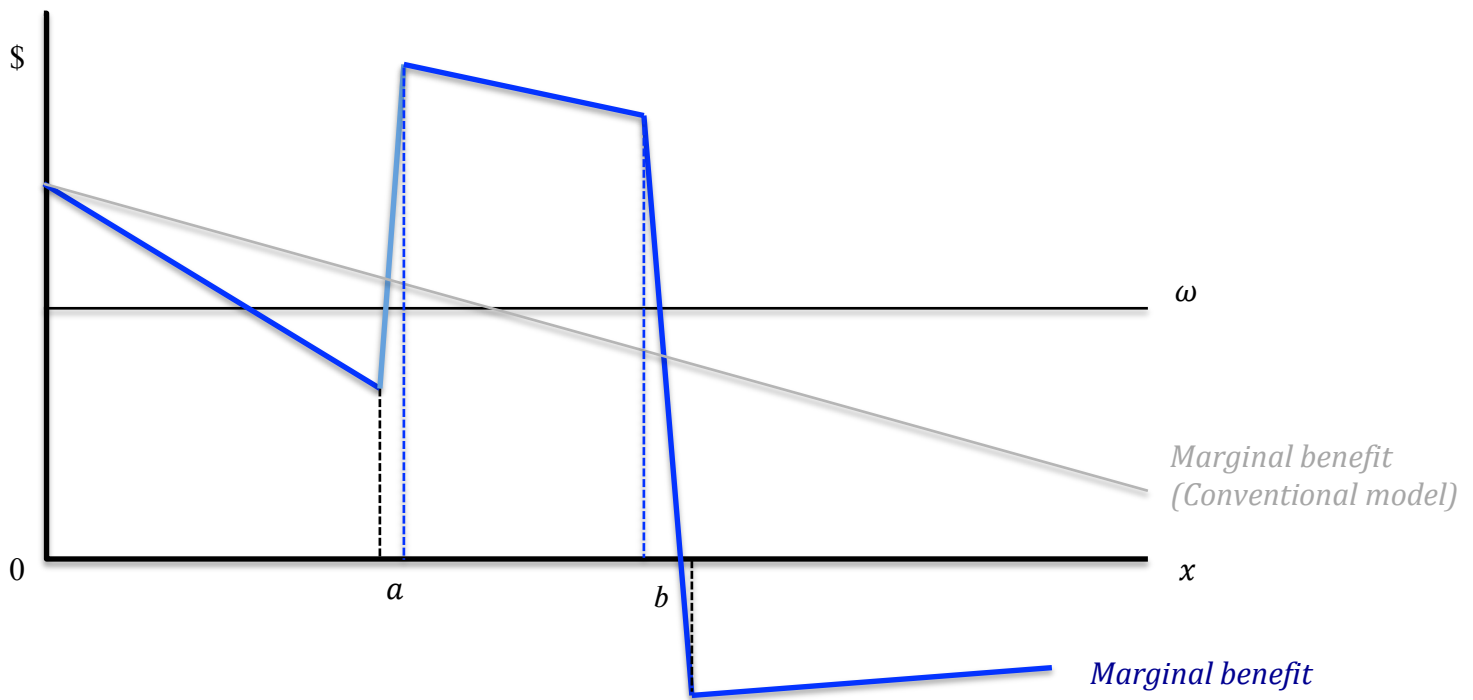
<sup>169</sup> Naturally, threshold effects can lead to discontinuous costs and benefit functions (at the tipping points), even when the precaution itself is continuous. We discuss such a case in the following example.



Figure III.4 roughly illustrates the total expected harm function of administering *XYZ* (in blue) juxtaposed to the total expected harm function of a drug that follows the assumptions of the conventional model (in grey);<sup>170</sup> and

Figure III.5 roughly illustrate the social costs of harm and precaution as a function of administering *XYZ* (in blue) juxtaposed to the same functions of a drug that follows the assumptions of the conventional model (in grey).

Figure III.2: Marginal Cost and Benefit of Administering *XYZ*



<sup>170</sup> The aggregated expected harm function (Figure III.3) is, obviously, the inversion of the expected benefit function (Figure III.4). We illustrate both here for clarity purposes.

Figure III.3: Total Benefit as a Function of Administering XYZ

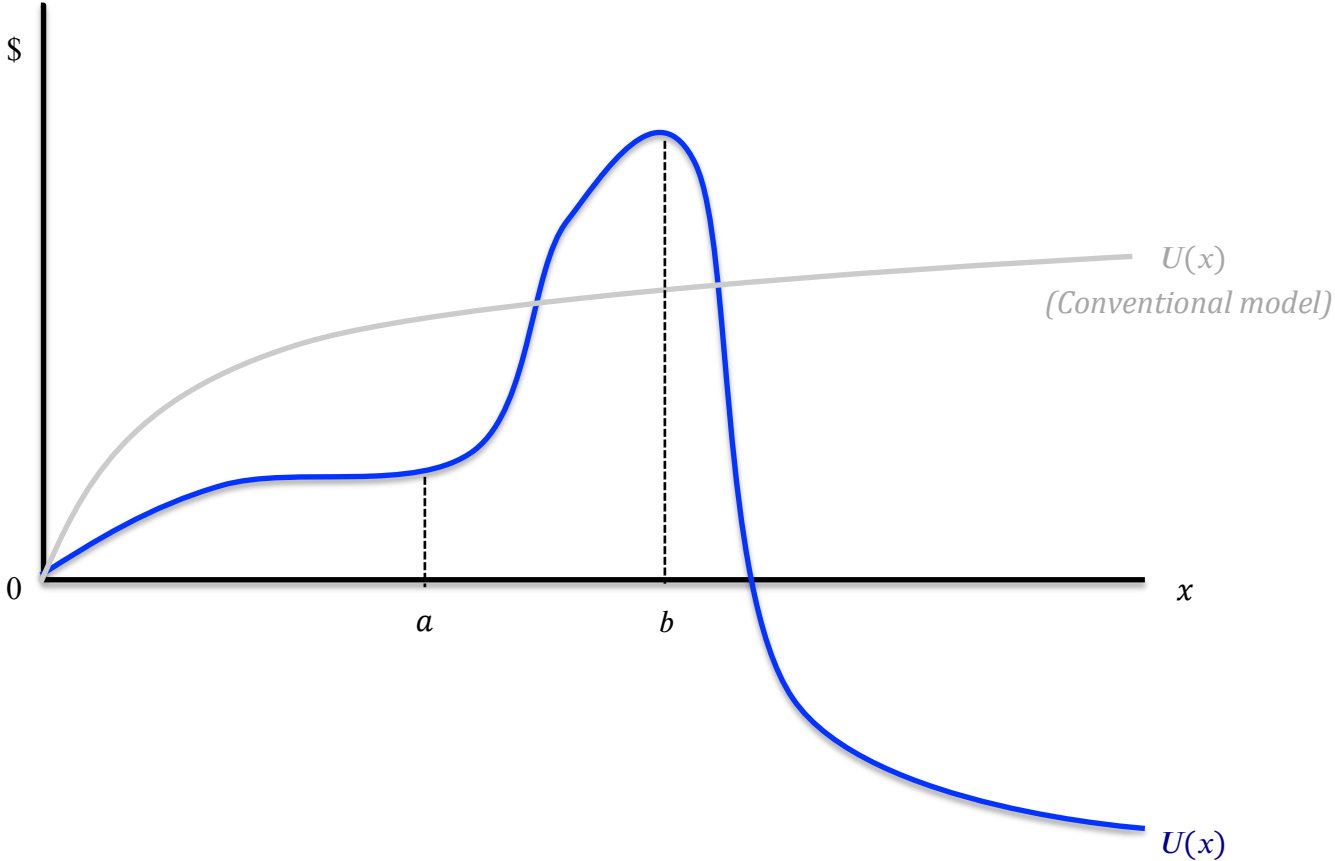


Figure III.4: Total Expected Harm as a Function of Administering XYZ

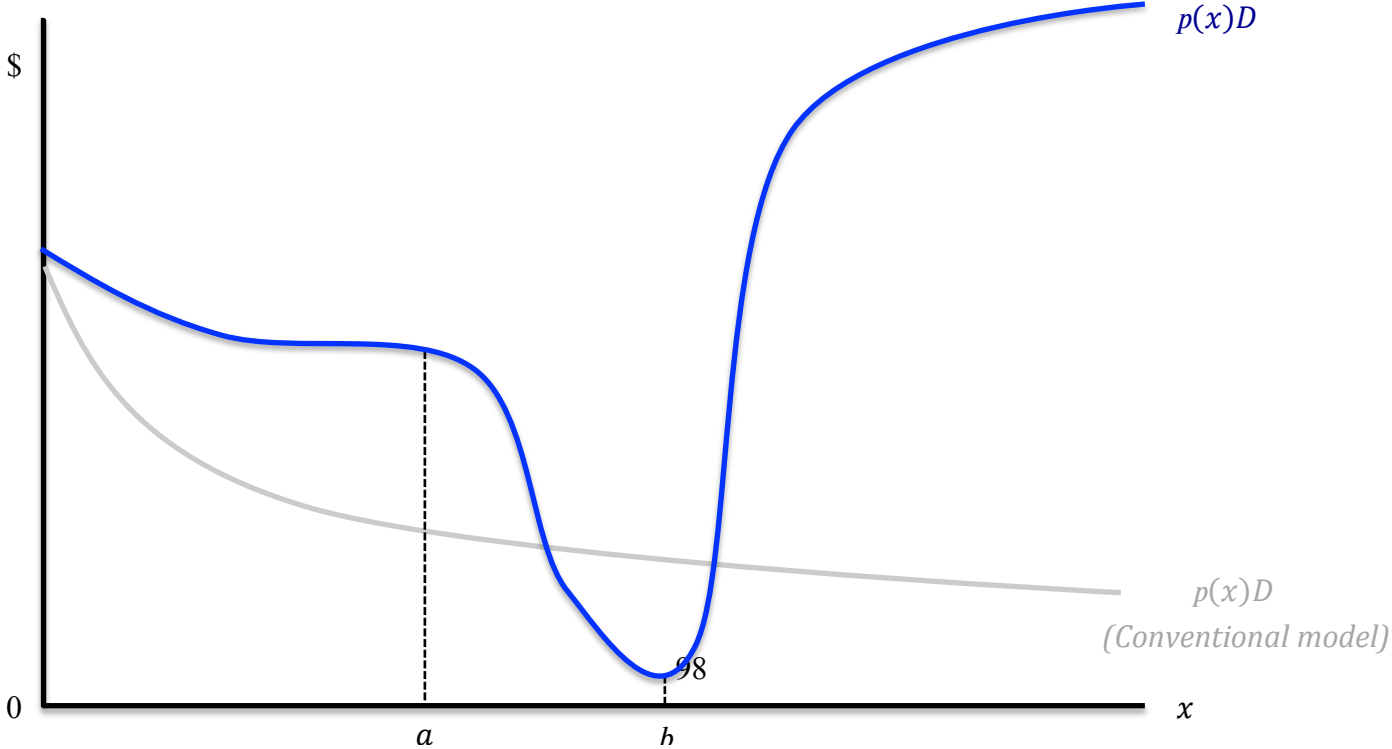
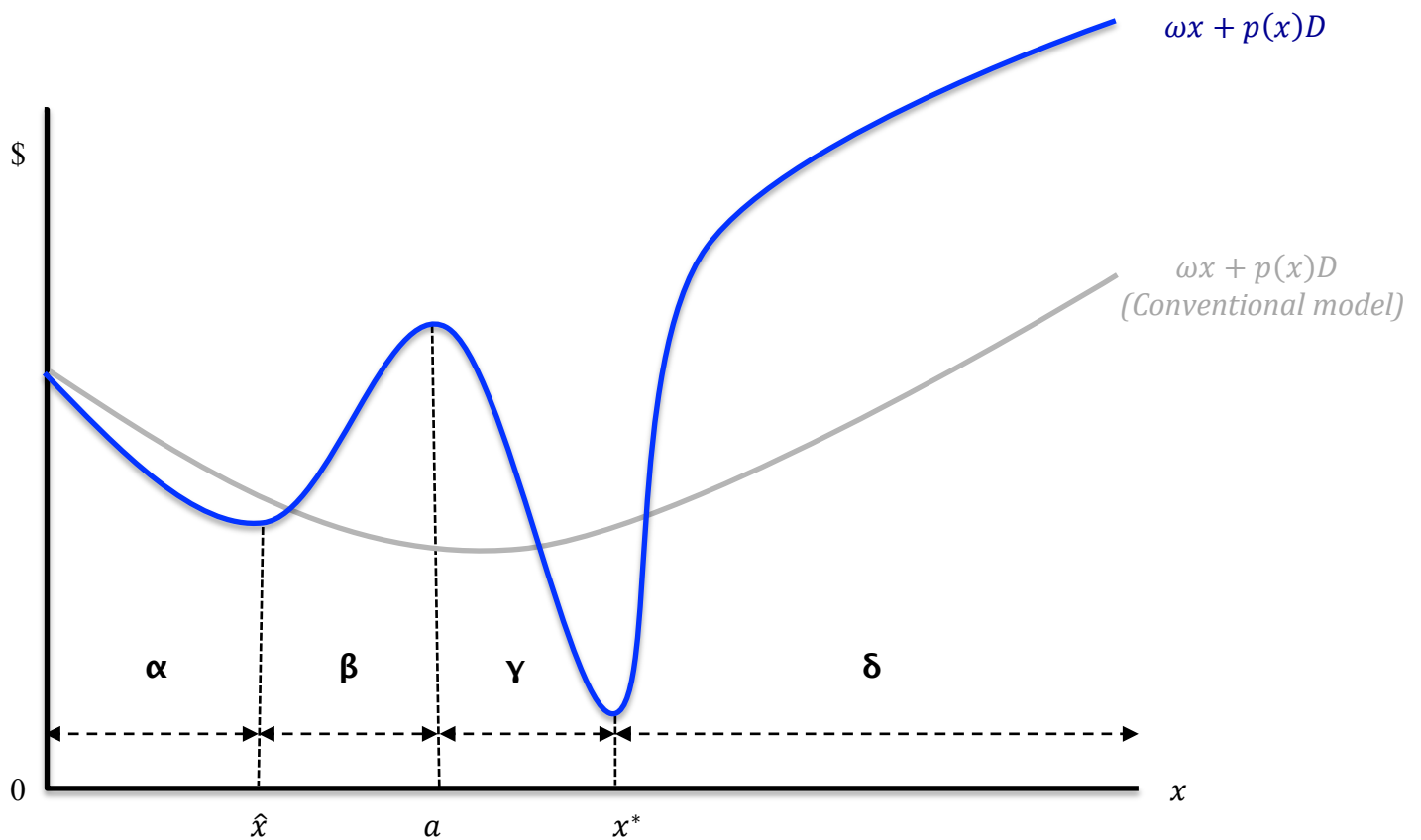


Figure III.5: Social Costs as a Function of Administering  $XYZ$



The total social costs function of  $XYZ$ , displayed in Figure III.5, is especially enlightening, and we can conduct our analysis on its basis. Notice that unlike the conventional model, the social costs function of  $XYZ$  is not monotone, and displays a local minimum (denoted  $\hat{x}$ ) anteceding a local maximum (at Threshold  $a$ ) and the global minimum ( $x^*$ ). The two minima and local maximum partition the curve into four sections, denoted  $\alpha$ ,  $\beta$ ,  $\gamma$  and  $\delta$ .

Sections  $\alpha$  and  $\beta$  represent  $XYZ$ 's social costs function before Threshold  $a$ , and not surprisingly display a similar pattern to that of the conventional model, *i.e.* a U-shaped strictly

convex cost function.<sup>171</sup> Section  $\gamma$  depicts a sharp decline in social costs as a result of *XYZ*'s heighten positive effect past Threshold a, which more than compensates for the additional cost of the drug. Section  $\delta$  depicts a sharp increase in social costs, corresponding with the *XYZ*'s adverse effects past Threshold b.

### **i. NORMATIVE REFLECTIONS**

How would the two approaches to negligence adjudication review this case? For the aggregated approach, the answer is simple—It would conclusively set the judicially required level of care ( $\tilde{x}$ ) at the global optimum  $x^*$ . If the defendant does not administer *XYZ* at least at  $x^*$ , she would be found liable. Notice also that, as a result of the adverse effect of the drug past Threshold b, a defendant might be considered negligent for administering too much of the drug, not only too little. If the defendant administers *XYZ* at a level at which it is toxic, *i.e.* at some level after  $x^*$  where *XYZ* has a negative marginal benefit, she would also be found liable.<sup>172</sup>

It is perhaps worth reiterating this particular feature—a defendant can sometime be negligent for taking either too much or too little of the same precaution. Ordinarily, the due care mark is one-sided, and taking additional precaution beyond the point of due care does not constitute a breach of duty. In those cases, going beyond the call of duty is not actionable, as it conveys a positive (though socially inefficient) externality on the potential plaintiff. Under the

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<sup>171</sup> We assume that the first intersection of marginal costs and benefits occurs before Threshold *a*, as illustrated in Figure III.2.

<sup>172</sup> This is not a fundamental problem in and of itself, as we can always reverse the x-axis and consider taking less of the drug as additional precaution. The interesting element in this example is that the two thresholds make it so that a defendant can be negligent for taking too much or too little of a particular precaution. As will soon become clear, the example also illustrates the difficulties in limiting a marginal analysis to additional precautions, rather than alternative ones.

conventional model, going above  $x^*$  does not create entitlement, liability or claims for the potential plaintiff.<sup>173</sup> When the assumptions of the conventional model are not met, however, things radically change. In reality, there is such a thing as to “desire too much of a good thing.”<sup>174</sup>

As for the marginal approach, it would review this case very differently. To see this, recall that the marginal approach applies a forward-looking and highly short-run (“marginal”) review. The deciding criterion under the marginal approach is simply the angle of the social costs slope (or the relative positions of the marginal curves) at the precaution level taken by the defendant. When the slope of the social costs curve is negative ( $\omega + p_x(x)D < 0$ ), the defendant is deemed negligent, and when it is not negative ( $\omega + p_x(x)D \geq 0$ ), the defendant is deemed not negligent.

When applied to our example, the marginal approach would find the defendant liable when taking precautions that fall in sections  $\alpha$  and  $\gamma$ , and not liable for precaution levels that fall in sections  $\beta$  and  $\delta$ . Thus, a defendant subject to the marginal approach would alternate between liability and no liability zones as she increases her precaution. She would be found liable in section  $\alpha$  (between 0 and  $\hat{x}$ ), not liable in section  $\beta$  (between  $\hat{x}$  and Threshold a), liable in section  $\gamma$  (between Threshold a and  $x^*$ ), and then again not liable in section  $\delta$ .

The notable difference between the aggregated and marginal approach therefore lies in section  $\beta$ . In section  $\beta$ , the aggregated approach would find the defendant liable, while the marginal approach would render a not liable judgment. Stated differently, the marginal

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<sup>173</sup> Things are slightly more complicated when a single precaution is beneficial to one third party and detrimental to another. That problem is beyond the scope of our discussion here.

<sup>174</sup> William Shakespeare, AS YOU LIKE IT, Act IV, Scene 1, 124 (1600).

approach would not place liability on a defendant who has taken precaution at or past the local minimum ( $\hat{x}$ ), but has not reached or surpassed Threshold  $a$ ; while the aggregated approach would place liability in such a case.

Which is the preferable result here? The answer in this case, I believe, is clearly in favor of the aggregated approach. The aggregated approach creates efficient incentives for the defendant to invest at the socially optimal level ( $x^*$ ). The marginal approach, on the other hand, does not incentivize the defendant to go beyond the local minimum ( $\hat{x}$ ), and vindicates suboptimal behavior in section  $\beta$ . Furthermore, the marginal approach's avoidance of liability-assignment in section  $\beta$  might lead to absurd results, whereby a defendant will become liable due to an increase in her precaution level from section  $\beta$  to section  $\gamma$ , even though that increase conveyed a benefit on the plaintiff.<sup>175</sup>

To see this more clearly, consider two prospective defendants, Abby and Ben. Abby takes precaution at section  $\beta$ , and Ben takes precaution at section  $\gamma$ . If the marginal approach is applied, Ben would be found liable while Abby would be exempted from liability, even though Ben created a smaller risk to the plaintiff than Abby, and his actions might have even been socially superior. The result is that the marginal approach would incentivize players not to take socially efficient precautions beyond a local minimum, and in some cases impose liability on them for doing so.

The reason for this overt failing of the marginal approach goes back to its underlying assumptions. The conventional model only envisions U-shaped social costs functions, and therefore does not address the implications of local suboptimal minima, or inconsistencies in

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<sup>175</sup> Such a limited increase might be, in some cases, socially inefficient, but would nonetheless be beneficial to third parties.

the slope of the social cost curve. In this example, the marginal approach also fails due to its short-run view—it does not look beyond incremental slopes, and does not examine possible costs and benefits of non-marginal additions (or “jumps”) to precaution.

It is perhaps possible to amend the marginal approach to consider non-incremental wide changes in precaution levels. Such a modification, however, might in turn undercut some of the principle advantages of the marginal approach, such as reduced costs, and encounter similar practical problems to the ones facing the aggregated approach. In any case, this adjustment would only be useful in limited circumstances, predominantly where local minima or discontinuities precede the global optimum. When a local minimum is postliminar to the global optimum, the resulting normative challenges go deeper, as the following chapter demonstrates.

**b. CASE STUDY B: LOCAL MINIMA POSTLIMINAR TO THE GLOBAL OPTIMUM**

**ii. EXAMPLES AND ILLUSTRATIONS**

Are there scenarios in which the above problem occurs in reverse order? Are there conceivable cases in which a local minimum occurs after the global optimum? The answer to that is, surely yes. In the following, we will start with briefly illustrating three such examples, and then reflect on the normative difficulties they bring. The first example will discuss continuous threshold effects in benefit functions; the second will discuss discontinuous threshold effects in benefit functions; and the third will illustrate discontinuous threshold effects in costs functions. A normative exploration will follow.

### Example III: Continuous Threshold Effects in Benefit Functions

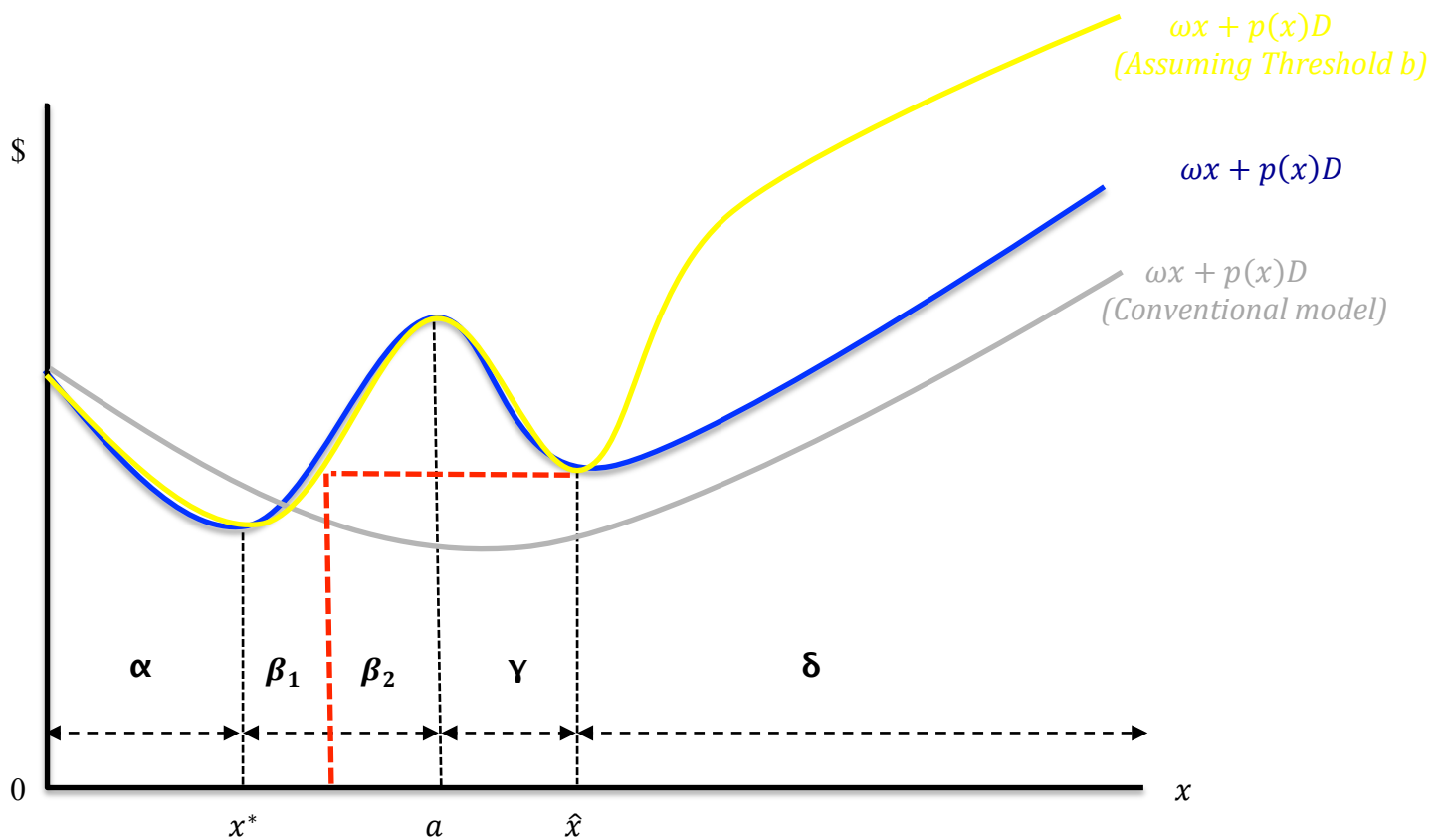
It is not difficult to envision examples of continuous threshold effects in benefit functions that result in a global optimum followed by a local minimum. For an easy example, all that is required is to redefine our above example regarding the *XYZ* drug by limiting the positive effect of the drug past Threshold  $a$ . Consider the following:

A pharmaceutical drug, *LRL*, presents with a continuous saddle benefit function—it abides by the rule of diminishing marginal returns until it reaches a particular threshold (Threshold  $a$ ), at which point the marginal benefit upturns for a limited range, and then continues to diminish. The first intersection of marginal costs and benefits occurs prior to Threshold  $a$ . Overall, the social optimum of administering *LRL* occurs before Threshold  $a$  is reached, and the social cost of any additional precaution past the first intersection of marginal costs and benefit, including past Threshold  $a$ , is suboptimal.

Figure III.6 illustrates the social costs function derived from such a case (in blue), juxtaposed to the social costs function of the conventional model (in grey). The yellow curve illustrates the social costs of *LRL* had it presented with a second threshold (Threshold  $b$ ) where it would have become toxic.



Figure III.6: Social Costs as a Function of Administering *LRL* (Continuous Threshold Effects in Benefit Function)



Example IV: Discontinuous Threshold Effects in Benefit Functions

Similar results can manifest when a precaution’s benefit function includes discontinuous thresholds. This is especially prevalent, as Part IV will soon explicate, in multidimensional frameworks and when different precautions interact.

Briefly, assume for the purpose of our discussion that  $x$  represents the overall investment level in precautions, rather than the measure of a single type of precaution, and that the defendant takes the *ex-ante* optimal set of precautions for each investment level.<sup>176</sup> Assume

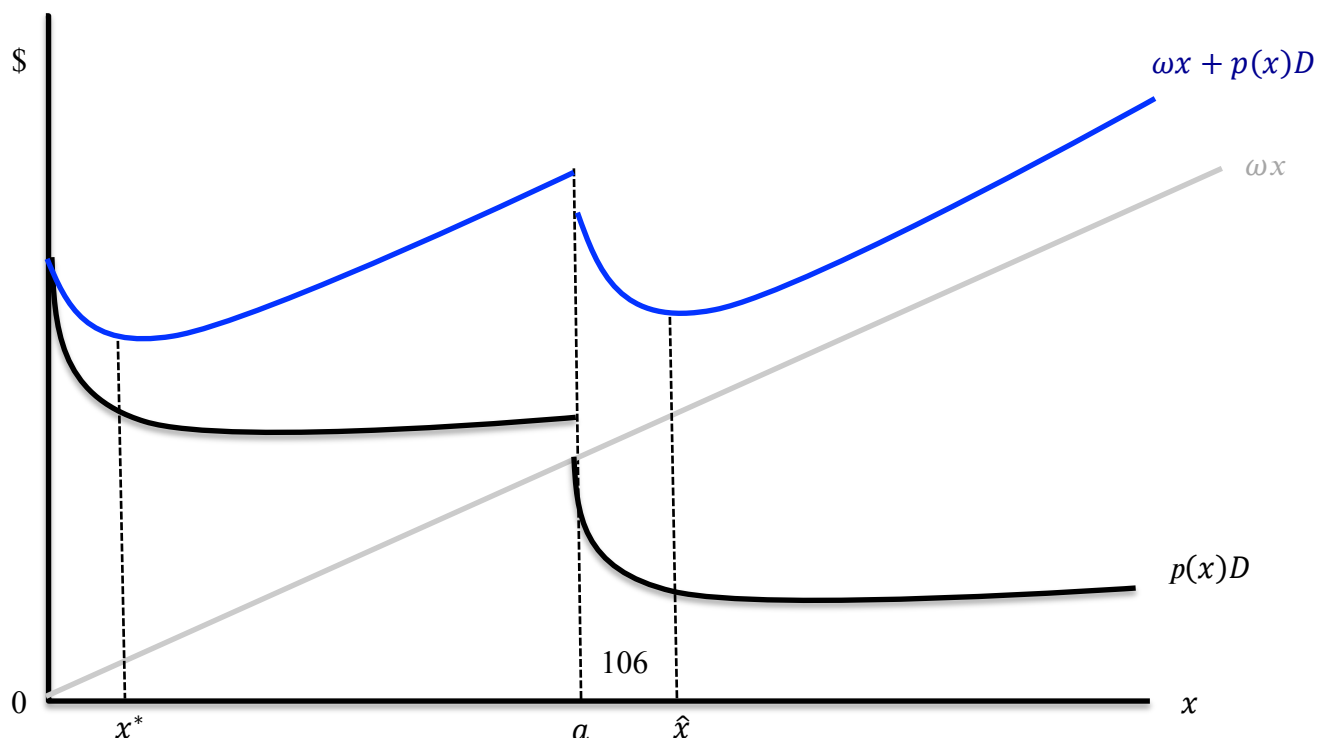
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<sup>176</sup> As discussed in Part IV, the optimal set of precautions for each investment level might vary when past actions are taken as given or when an unconstrained analysis is performed.

also that a particular precaution-device, Machine  $a$ , is only available once a certain investment level is reached. Thus, Machine  $a$  is a discrete precaution that is obtainable only past a specific cost threshold (Threshold  $a$ ). After Machine  $a$  is purchased, additional investments can improve its performance.

In this example, we assume that the total harm  $(p(x)D)$  as a function of taking precaution is continuous, downward sloping and convex before Threshold  $a$  is reached. Thus, the marginal return on investment in precaution is diminishing. Threshold  $a$  inserts a discontinuity to the function, coupled with a sharp decline in expected harm. The marginal return on investment in precaution also improves past Threshold  $a$  (as a result of possible improvements in the performance of Machine  $a$ ), but diminishes for any investment level past Threshold  $a$ . Figure III.7 illustrates the total cost of precaution (in grey), total harm (in black) and social cost (in blue) functions for this example:

Figure III.7: Total Precaution Costs, Harm and Social Cost as a Function of Precaution  
(Discontinuous Threshold Effects in Benefit Function)



### Example V: Discontinuous Threshold Effect in Costs Functions

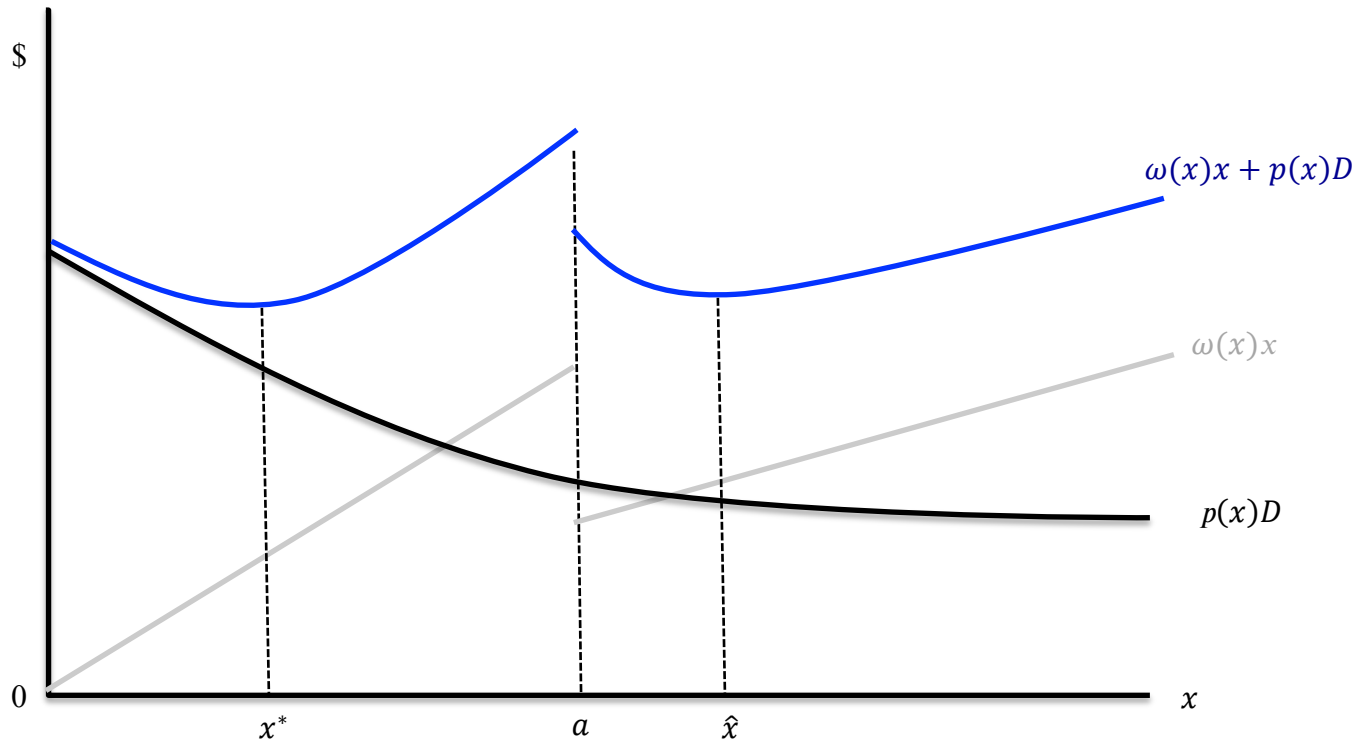
As a third example, consider a case where a discontinuous threshold presents at the precaution's cost function, rather than the benefit or harm side. Common examples of this scenario are quantity or bulk discounts, as well as other manifestations of economics of scale. When a price discount is granted past a certain investment or quantity, and affects the costs of all precautions (not only precautions past the discount mark), the overall social cost function will be somewhat similar to our above examples.

For this example,  $x$  will represent the number of precaution units taken by the defendant. The marginal return on precautions is assumed to be continuous and diminishing for every  $x$ . However, once the number of precaution units reaches a certain threshold (Threshold  $a$ ), the price per unit of precaution drops for all units. Threshold  $a$  therefore creates a discontinuity in the cost of precautions function, and unlike our previous example we no longer assume that the marginal cost of precautions ( $\omega$ ) is constant.

The slope of the cost curve ( $\omega(x)$ ), or the marginal cost of precautions, is steeper before Threshold  $a$  than it is after it. Figure III.8 illustrates the total cost of precaution (in grey), total harm (in black) and social cost (in blue) functions for such a case:

Figure III.8: Total Precaution Costs, Harm and Social Cost as a Function of Precaution

(Discontinuous Threshold Effects in Costs Functions)



### iii. NORMATIVE REFLECTIONS

What are the normative implications of scenarios where a local minimum presents after the global optimum? Consider first, as before, how the two approaches to negligence adjudication would review these cases. To facilitate a comparison with our analysis of Case Study A, we will discuss Example III regarding the *LRL* drug and continuous functions, illustrated by the blue curve in Figure III.6.

In reviewing Example III, the aggregated approach would, as always, set the judicially required level of care ( $\tilde{x}$ ) at the global optimum,  $x^*$ . If the defendant administers *LRL* at a

lower level than  $x^*$ , she would be found liable.<sup>177</sup> Thus, the defendant would be found liable if she takes precaution that fall in section  $\alpha$ , and not liable for precaution levels that fall in sections  $\beta$ ,  $\gamma$  and  $\delta$ .

The marginal approach, on the other hand, would only review the slope of the social cost function at the precaution level taken by the defendant, and find the defendant negligent if that slope is negative. Therefore, the marginal approach would find the defendant liable if she takes precautions that fall in sections  $\alpha$  and  $\gamma$ , and not liable if she takes precautions that fall in sections  $\beta$  and  $\delta$ . As before, a defendant subject to the marginal approach would alternate between liability zones as she increases her precaution. She would be found liable in section  $\alpha$  (between 0 and  $x^*$ ), not liable in section  $\beta$  (between  $x^*$  and Threshold  $a$ ), liable in section  $\gamma$  (between Threshold  $a$  and  $\hat{x}$ ), and then again not liable in section  $\delta$ .

The major difference between the two approaches now lies in section  $\gamma$ . In this section, the aggregated approach would not place liability on the defendant (as precautions in section  $\gamma$  exceeds the optimal level of care  $x^*$ ), while the marginal approach would place such liability (as the slope of the social cost curve in section  $\gamma$  is negative until  $\hat{x}$  is reached). The marginal approach would therefore require a defendant who has taken precautions beyond the socially optimal point to, sometimes, “go the extra mile” and increase her investment in precaution up to the nearest local minimum.

Which is the preferable approach here? On one hand, a marginal analysis seems justified in this case, as it creates efficient short-run incentives for the defendant in section  $\gamma$ .

To see this, notice that once a defendant’s investment in precaution goes beyond Threshold  $a$ ,

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<sup>177</sup> We assume here that *LRL* does not become toxic past a second threshold. If that were the case, the defendant might also be considered negligent for administering the drug past  $x^*$ , when such addition would convey a negative externality on third parties.

additional investments become marginally and socially warranted. Applying the aggregated standard would not incentivize defendants to take additional cost-justified precautions in section  $\gamma$ , and would therefore fail to bring about efficient outcomes from an *ex-post* perspective, *i.e.* assuming the defendant's past investment.

Adhering to the aggregated approach in section  $\gamma$  would therefore go against conventional economic wisdom, which generally calls for the exclusion of sunk costs from cost-benefit analyses. According to this argument, the only relevant consideration is whether—existing conditions assumed—the defendant could have efficiently taken additional precautions. By applying a constrained optimization process, and taking existing settings into account, the marginal approach creates efficient *ex-post* incentives in section  $\gamma$ , while the aggregated approach fails to do so.

On the other hand, applying the marginal approach to these settings might lead to problematic and unjust results, at least through a common sense, long-run and doctrinal framework. If the marginal analysis is applied, a defendant in section  $\gamma$  would be found liable as a *de-facto* result of taking precautions beyond  $x^*$ , *i.e.* as a result of going above and beyond her original duty. If it were not for a defendant's original overinvestment in precaution—which was beneficial to the plaintiff—additional cost-justified precautions would not have been possible. Avoiding socially inefficient positive externalities, and keeping precaution levels at  $x^*$  or in section  $\beta$ , are therefore ironically required by the marginal approach in order to avoid liability.

To see this tension more clearly, consider two possible defendants, Abby and Ben. Abby sets her precaution level at the social optimum  $x^*$ , while Ben takes more precautions than socially optimal and sets his precaution level in section  $\gamma$ . A marginal approach would find

Ben in breach of duty, but not Abby, even though Ben created a smaller risk to the plaintiff. Holding Ben liable in these circumstances would therefore go against accepted tort conventions and intuition. Furthermore, from a dynamic perspective, holding Ben liable for his past miscalculation or overinvestment might alter his *ex-ante* incentives and decision making patterns, and create an unwarranted incentive against taking extra-precautions. It is doubtful whether such deterrence against socially inefficient positive externalities is deserved.

The normative dilemma presented by this setting can therefore be phrased as follows— if a defendant takes one step beyond the optimal and legally required level of care, can she be obliged to take two?

Lastly, notice that both approaches fail to create efficient short-run incentives in section  $\beta_2$ . In section  $\beta_2$ , the defendant can efficiently increase her investment in precaution by moving to  $\hat{x}$ .<sup>178</sup> The aggregated approach does not incentivize such efficient additional investment as the socially optimal level of care ( $x^*$ ) has been surpassed; and the marginal approach does not incentivize such additional investment, as it is not incrementally cost-justified (as the slope of the social costs curve in section  $\beta_2$  is positive). Thus, the marginal approach falls short of offering efficient short-run incentives even under its own terms and logic, and does not give adequate weight to the possibility of non-incremental efficient changes (“jumps”). As before, this failure of the marginal approach can perhaps be mended, though not without cost.

To summarize our results here, both the aggregated and marginal approaches operate as double-edged swords. The aggregated approach is instrumental in preventing inefficient

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<sup>178</sup> Or even by moving to section  $\gamma$ , depending on the defendant’s precaution level (though movement to section  $\gamma$  will not result in equilibrium until  $\hat{x}$  is reached).

strategic behaviors in cases where a local minimum precedes the global optimum, but might create inefficient short-run incentives in scenarios involving sunk costs, and when the global optimum precedes a local minimum. The marginal approach, on the other hand, fails to create efficient long-run incentives in cases where a local minimum precedes the global optimum, but might create efficient short-run incentives in scenarios involving sunk costs, and when a the global optimum precedes a local minimum.

Whether or not the marginal or aggregated approach should be determinative is therefore case sensitive and highly fact contingent. The difference in outcomes arrived by the two forms of analysis does, however, exemplify a paradigmatic normative concern—an innate tension between short and long-run review, and between constrained and unconstrained optimization processes. This tension manifests in many of the critical models developed in this thesis. The same tension underlies the contention, advanced in Part V, that no single optimization method is perfectly suited for all real-world settings.

Perhaps not unexpectedly, this tension has largely gone unnoticed in conventional scholarship with regards to negligence standards and adjudication.<sup>179</sup> The reason for this lacking goes back, as before, to the underlying assumptions of the conventional model. When the orthodox economic presuppositions are assumed, the theoretical distinction between local minima and global optimum is devoid of all practical meaning, and the normative implications and associated difficulties of the disparity between them is easily missed.

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<sup>179</sup> For a related piece, discussing a similar tension in the context of bilateral settings, and specifically sequential actors, activity levels and causation see Anderson, *The Missing Theory of Variable Selection*, *supra* note 22, at p. 263 (“The general problem is that we want tort law to induce a social optimum under multiple sets of constraints: both when the existence of the first party’s negligence is still a variable and also once it has already occurred and is taken as a given”).



## F. THE ANNA KARENINA PRINCIPLE

*“Happy families are all alike; every unhappy family is unhappy in its own way.”*<sup>180</sup>

Lev Tolstoy’s phenomenal opening to his masterpiece ANNA KARENINA encapsulates a general wisdom worth noting—predictable homogeneous settings are fragile and rare, highly contingent on the simultaneous existence of multiple factors. When a particular model’s preconditions are not explicitly met, even to a small degree, it might break into inimitable fragments and present with unexpected singular outcomes.

The Anna Karenina Principle is applicable to an array of natural and social schemas and endeavors. It instructs that minor deficiencies, flaws and idiosyncrasies in any complex system may radically alter their function, and render attempts of generalization or uniform evaluation extraneous. Put differently, when slight changes occur in the underlying foundations of any structure, drastic alterations and fluctuations in behavior might follow. More importantly, the outcome of these alterations is often unique, unforeseeable and highly case-specific.

For our purposes here, the principle illustrates the fragility and limitations of the conventional model. The conventional model requires that all of its particular underlying assumptions subsist, and is only applicable when they are all met. Such alignment is, arguably, rather infrequent, as slight idiosyncrasies and particularities commonly present in most systems. Therefore, the principle predicts that the conventional model will only apply in limited circumstances, and that reality present with a vast array of exceptional, non-orthodox settings and challenges. Continuous, single-dimensional and monotonically convex functions are therefore all alike; but every other social cost function is unique in its own way. Part IV continues to demonstrate how and why.

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<sup>180</sup> Lev Nikolayevich Tolstoy, ANNA KARENINA, Chapter 1, Line 1 (1878).

**PART IV:**  
**THE ASSUMPTIONS OF THE CONVENTIONAL MODEL RELAXED AND THE  
FAILINGS OF THE MARGINAL APPROACH:**  
**MULTIDIMENSIONAL FRAMEWORKS AND INTERACTING PRECAUTIONS**

**A. INTRODUCTION AND CHAPTER PROGRESSION**

In Part III, we demonstrated that the marginal approach hinges entirely on narrowly construed prerequisites, and began to systematically define the parameters and boundaries of these prerequisites. We then moved to explore in further depth the convexity, monotonicity and continuity assumptions, and the possible inefficiencies and detrimental outcomes that might transpire from the application of the marginal approach to setting where these assumptions are not met.

In Part IV, we turn our attention to two additional underlying assumptions of the conventional model: (i) single dimensionality, and (ii) orthogonality and predeterminacy. According to the single dimensionality assumption, precautions are one-dimensional, and can be fully and accurately commensurated along a single axis. According to the orthogonality and predeterminacy assumption, precautions are uncorrelated, so that the marginal efficiency of any given precaution is not affected by taking other precautions.

Part IV unfolds as follows. We begin by discussing the single dimensionality assumption, and demonstrate the multidimensional nature of precautions in most real-world negligence settings. In doing so, show that different precautions are often substitutable, and explore the ramifications of that quality in the negligence context. We then move to model a supply side theory of negligence, using tools and terms laid out in production theory in microeconomics. The basic contention here is that tortfeasors can and should be thought of as

manufacturers of care, and that terms such as isoquants of care, marginal rate of technical substitution and production hills can significantly and meaningfully expand our understanding of the precaution side (or “*B*-side”) of the Hand Formula. From this point, we explore the key normative difficulties resulting from multidimensional negligence frameworks, and illustrate these normative exertions thorough a review of *The Jerusalem Municipality v. Mimoni*.<sup>181</sup> We conclude this section by noting the ways in which the single-dimensional paradigm might obscure both the actual characteristics of negligence puzzles and the optimization process required to solving them, and reflect upon such impediments as variable selection, specific versus general regulation and short-run versus long-run optimization.

After completing our discussion of multidimensional frameworks, we move to explore the orthogonality and predeterminacy assumption, delving deeper into the prevalent case of interacting (correlated) precautions. In doing so, we attempt to systematically categorize the possible relationships between precautions, and model them to include: (i) independent (uncorrelated) precautions; (ii) complementary precautions; (iii) mutually exclusive precautions; and (iv) interacting precautions, which are further divided between: (a) negatively synergetic precautions; (b) overlapping precautions; and (c) positively synergic precautions. For each type of interaction, assorted suboptimal equilibria, foreseeable strategic behaviors and expected inefficiencies from a misguided application of the marginal approach are uncovered and illustrated. As in other parts of this thesis, the *Hendricks Case*<sup>182</sup> will be used as the principal example in this section.

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<sup>181</sup> C.A. 1068/05 *The Jerusalem Municipality v. Mimoni*, (14.12.2006) (my translation; hereinafter: “*Mimoni*,” “*The Mimoni Case*” or “*The Jerusalem Municipality v. Mimoni*”). By way of disclosure, the writer clerked for the presiding judge, Chief Justice Aharon Barak, at the time this judgment was issued.

<sup>182</sup> *Hendricks v. Peabody Co.*, *supra* note 8.

Throughout the normative analysis in this part, we revolve around two notions embedded in the innate logic of the marginal approach: (i) the sufficiency and equivalency of a short-run (“myopic”) analysis; and (ii) the sufficiency and equivalency of a constrained (“memoryless”) analysis. The first notion assumes that an incremental short-run review is necessary and sufficient from optimal results to be reached in all negligence settings. The second assumes that a constrained (or *ex-post*) review is necessary and sufficient for optimal results to be reached in all negligence settings.<sup>183</sup> Our discussion demonstrates why and when these notions are untrue, and further explores the impact of interacting precautions, path-dependencies, sequential settings and switching costs on negligence puzzles. We conclude Part IV by discussing the conditions for commensurating multidimensional precautions to a single axis.

## **B. THE SINGLE DIMENSIONALITY ASSUMPTION AND MULTIDIMENSIONAL SETTINGS**

### **a. THE GENERAL FRAMEWORK**

The conventional model critically assumes that precautions are “one dimensional.” What this means in practice is that precautions are understood to be either (i) of one continuous “type”, such as the speed of a car, the strength of a bridge’s foundations or the length and frequency of safety trainings; or at the very least (ii) can be fully and accurately commensurated along a single axis, denoting a general precaution level or level of investment in precaution.

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<sup>183</sup> But see Shavell, *Economic Analysis of Accident Law*, *supra* note 12, at pp. 77-79, 91-93 (discussing distinguishable cases of prior acquisition of information or willful intoxication); and Section V.G. hereinafter.

This assumption is pivotal to the fundamental design of the conventional model. For unilateral precautions (where only the tortfeasor can take precautions), the conventional model is designed to solve a single variable problem—“was the defendant’s level of care ( $x$ ) sufficient or insufficient.” The method employed by the marginal approach to answer this question—“could the defendant have taken a single, additional, cost-justified precaution”—also smacks of single dimensionality, and does not provide room for multidimensional solutions. Single dimensionality is, indeed, coded in the DNA of the conventional model.

In reality, however, precautions appear in different types, shapes and sizes, and as the following sections will soon reveal are often irreducible to a single variable or continuum; at least not if the model is to reach efficient outcomes. To “take care” in a particular setting usually means exercising different types of precautionary care measures. Each type of precaution can, in turn, be continuous or discontinuous, and may present with individually convex or non-convex functions. Importantly, as we shall soon explore, different precautions are often substitutional, in the sense that the same level of care or safety output can be achieved by trades-off between different precautions.<sup>184</sup> Recognizing the diversity of different types of precautions is a crucial first step to solving negligence puzzles.<sup>185</sup>

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<sup>184</sup> The possibility of substituting precautions is generally unexplored in legal economic scholarship. For a related idea, see Robert D. Cooter and Ariel Porat, *Lapses of Attention in Medical Malpractice and Road Accidents*, 15 THEO. INQ. L. 329 (2014) (hereinafter: “*Lapses of Attention in Medical Malpractice and Road Accidents*”) (discussing substitutional effects between variables in the context of players’ incentives to reduce prospective liability for lapses, and different probabilistic distribution scheme of labor and capital). Additionally, Gilo and Guttel’s model regarding the risk of insufficient activity coupled with suboptimal care (discussed hereinafter, in Part V.F.) may be viewed as a product of an interplay between these two factors, allowing for identical levels of care (safety) to be achieved through different bundles of precautions. See David Gilo and Ehud Guttel, *Negligence and Insufficient Activity: The Missing Paradigm in Torts*, 108 MICH. L. REV. 277 (2009) (Hereinafter: “*Negligence and Insufficient Activity: The Missing Paradigm in Torts*”).

<sup>185</sup> To the extent the conventional model recognizes the multidimensional nature of precautions, it does so by excluding certain types of precautions from negligence analysis, deeming them “activity level” variables. As Section V.F. shows, this confusing term facilitates further obscuring the true nature of negligence puzzles, and the critical conundrums facing lawmakers in solving them. Additionally, some reference to multidimensionality can be found in the

Different types of precautions emanate different types of challenges to negligence cost-benefit analysis. Such challenges include: (i) normative and distributional dilemmas and restraints; (ii) informational and decision-making costs; (iii) court-institutional limitations; (iv) timeframe definition and long-run versus short-run conflicts; (v) difficulties pertaining to the observability and verifiability of variables; (vi) difficulties pertaining to care versus “activity level” classifications; (vii) difficulties pertaining to care versus lapses, or “first order” versus “second order” classifications; (viii) difficulties pertaining to care versus “self-risk” definitions; and more. Many of these complications have been addressed, at least to some extent, in economic scholarship, and are therefore not an object of an in-depth exploration here.

To illustrate the workings of multidimensional precautions in real world settings, and the intrinsic multivariable complexity of most negligence puzzles, consider the run-of-the-mill example of car accidents. The expected harm from car accidents is a function of myriad precautions, each of which entails specific challenges to cost-benefit analysis (mentioned and discussed in footnotes):

- (i) The speed of the car at the time of the accident (precaution  $x$ ): a continuous and likely monotonically convex precaution, which might involve timeframe definition and short-term over long-term difficulties.<sup>186</sup>
- (ii) The type and quality of brakes and wheel-tires (precautions  $y$  and  $z$ ): discrete or continuous variables with a continuous or lumpy efficiency functions.<sup>187</sup>

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conventional scholarship pertaining to bilateral precautions and strategic settings involving two or more players (see, for instance, Guttel, *The (Hidden) Risk of Opportunistic Precautions*, *supra* note 39, and the many sources listed there and in *supra* note 95). The possibility of such multidimensional and interacting precautions within a unilateral setting has, however, generally eluded economic scholarship.

<sup>186</sup> For instance, it could be that the speed at the time of impact was low, but the average speed during the minute (or hour) before the accident was high. See also Cooter and Porat, *Lapses of Attention in Medical Malpractice and Road Accidents*, *supra* note 184, at p. 4.

- (iii) Installation and type of Anti-Lock Braking System (ABS), seatbelts, and driver, passenger, knee and side airbags (precautions  $q$ ,  $r$  and  $s$ ): binary or discrete durable variables,<sup>188</sup> the last two broadly affecting only the driver's self-risk.<sup>189</sup>
- (iv) The type of car driven, its design standards and crash-testing score (precaution  $t$ ): a lumpy or continuous durable variable,<sup>190</sup> often disregarded for normative or practical reasons.<sup>191</sup>

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<sup>187</sup> As discussed in Part III, many precautions can be alternatively conceptualized as continuous or discontinuous. For instance, the quality and maintenance of wheel-tires and brakes can be thought of as continuous or discontinuous variables.

<sup>188</sup> On the distinction between durable and nondurable precautions, and its normative repercussions see Grady, *Why Are People Negligent?*, *supra* note 122, at p. 302; Grady, *Response, Another Theory of Insufficient Activity Levels*, *supra* note 163, at p. 32; and Steven Shavell, *On Optimal Legal Change, Past Behavior, and Grandfathering*, 37 J. LEGAL STUD. 37 (2008) (hereinafter: "*On Optimal Legal Change*").

<sup>189</sup> These precautions can be conceptualized a binary, discrete or even continuous, much like precautions  $y$  and  $z$  in this example. On self-risk versus joint risks see Cooter and Porat, *Does Risk to Oneself Increase the Care Owed to Others?*, *supra* note 24.

<sup>190</sup> Classification as continuous or lumpy hinges on, for instance, whether the variable denotes crash-testing scores (a continuous variable) or a vector ranking of different cars (discontinuous variable).

<sup>191</sup> The reason why the type of car variable is usually not taken into account in applying the Hand Formula is a matter for a separate discussion, and has only been loosely addressed in literature. In a nutshell, the reasons for this avoidance can be, for instance, (i) reliance on regulatory standards and enforcements, applying a judicial fiction that all regulatory-approved cars are equally safe; (ii) policy and distributive considerations. For instance, it might be socially unacceptable to allow a claim implying that a tortfeasor may drive faster when he or she owns a safer—and more expensive—car; (iii) The type of car might be thought to affect only the self-risk to the tortfeasor, which is often not taken into account by courts (see Cooter and Porat, *Does Risk to Oneself Increase the Care Owed to Others?*, *supra* note 24); (iv) reliance on market deterrence, the efficiency of the market and consumer choice to best incentivize car manufacturers; (v) limitations on judicial knowledge, resulting from the complexity of the field; (vi) different normative approach applicable to durable precautions, making the applicable legal standard closer to strict liability (see Grady, *Response, Another Theory of Insufficient Activity Levels*, *supra* note 163, at p. 32; Grady, *Why Are People Negligent?*, *supra* note 122; and more. See generally on this discussion, Porat, *Misalignments*, *supra* note 24; Anderson, *The Missing Theory of Variable Selection*, *supra* note 22, at pp. 256, 267, 282 (focusing on the empirical data required for making this decision: “[s]hould a court consider the choice of automobile in determining whether or not a driver was negligent? The conventional economic model of tort law provides no answer to this question... the right answer might depend on context-and industry-specific questions: Would failing to incorporate this variable encourage drivers to purchase unsafe automobiles? If so, how many more accident would result? Would potentially finding drivers negligent for the choice of automobile lead to take fewer precautions? Are there other accident-affecting variables that the decision to include or exclude the choice of automobile would affect?”).

As we shall soon explore, this avoidance might also be a expression of a highly constrained and short-run application of the marginal approach to multidimensional settings, where one observable and verifiable variable (such as the speed of the car at the time of the accident) is optimized irrespective of other precautions, *de-facto* assuming all other precautions are taken at a preordained or optimal level.

- (v) The route chosen by the driver (precaution  $u$ ): a lumpy variable, often disregarded for normative and practical reasons.<sup>192</sup>
  - (vi) The frequency of looking in the rearview mirror and speedometer (precautions  $v$ ): commonly considered non-observable and non-verifiable continuous and monotonically convex variables.<sup>193</sup>
  - (vii) The level of driving-proficiency and training of the driver (precautions  $w$ ): continuous or discrete “second order” variables, likely monotonically convex.<sup>194</sup>
- Driving proficiency might be non-observable or non-verifiable in some cases, disallowed for reasons of practicality, secondary effects,<sup>195</sup> court institutional limitations and decision-making costs, precluded in order to enhance a judgment’s precedential value,<sup>196</sup> or even viewed as part of the exogenous setting of risks.<sup>197</sup>

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<sup>192</sup> Amongst other reasons, a driver’s choice of route is often ignored in light of the short-run view of the conventional model (see Anderson, *ibid*, at p. 271). However, it is entirely possible for courts to take note of this variable in conducting negligence inquiry and apply a broader view the negligence optimization puzzle, as we discuss in Part V. The RESTATEMENT (SECOND) OF TORTS §297 (1965) also addresses this issue, within the confines of a single-dimensional view, noting that “There are many mountain roads which may properly be regarded as dangerous no matter how careful... the driver may be... there is an inescapable risk in driving down a narrow and ill-kept mountain road... particularly if... snow, or ice, has rendered the road slippery... Mere use of such route... may be negligent unless the utility of the route is very great.”

<sup>193</sup> For a discussion of such variables, in the context of activity levels see in Part V.F. hereinafter.

<sup>194</sup> On second order variables see Cooter and Porat, *Lapses of Attention in Medical Malpractice and Road Accidents*, *supra* note 184, at p. 4.

<sup>195</sup> On secondary effects see, for instance, Posner, *Cases and Economic Analysis*, *supra* note 16, at p. 231 (positing that applying standards based on individual cost functions might incentivize people not to improve their skills, as any improvement would also increase their duty of care).

<sup>196</sup> These arguments were invoked in the known case of *Fredericks v. Castora*, 241 Pa. Super. 211, 360 A.2d 696 (1976), noting:

“On appeal, plaintiff argued that the [two drivers] should be held to a higher standard of care than is usually applied to the operator of a motor vehicle.... In support of this position, reference is made to the evidence that both defendants were professionals who drove trucks for a living and had done so for over 20 years...

...A requirement that experienced truck drivers be subject to a higher standard of care does no impress us as being a useful concept to infuse into the law of



- (viii) Use of alcohol, drugs, hand-held mobile devices, driver’s fatigue and alert and other elements affecting the driver’s responsiveness and concentration (precautions *j*): continuous or discrete “second order” variables.<sup>198</sup>
- (ix) The number of miles driven over a particular time period (precaution *k*): a continuous and innately “activity level” (or frequency claim) variable, presenting with timeframe definition and short-term over long-term difficulties.<sup>199</sup>

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vehicle negligence. An understanding of the ordinary standard of due care applicable to the average motorists under the *multitude of changing circumstances* likely to confront today’s driver is *already difficult to grasp* and apply justly. To begin to vary the standard according to the driver’s experience would render the application of any reasonably *uniform standard* impossible...” (*ibid*, emphasis added).

<sup>197</sup> We address the issue of variable selection and the distinction between past constraints and variables in further detail hereinafter, in Section IV.B.g.

<sup>198</sup> For a discussion viewing frequency claims (affecting driver’s fatigue) as second order variables see John J. Donohue III, *The Law And Economics of Tort Law: The Profound Revolution*, 102 HARV. L. REV. 1047, 1062 (1989).

<sup>199</sup> See Susan Rose-Ackerman, *The Simple Economics of Tort Law: An Organizing Framework*, 2 EUR. J. POL. ECON. 91, 96-97 (1986); and Steven Shavell, *Strict Liability vs. Negligence*, 9 J. LEGAL STUD. 1, 2 (1980). The number of miles driven is a classic example of activity level, which affects the overall risk of accidents, yet is generally not taken into account by the negligence standard. See A. Mitchell Polinsky, AN INTRODUCTION TO LAW AND ECONOMICS 53 (3d ed. 2003) (“In practice . . . it often is not feasible to include the level of participation in the activity as an aspect of the standard of care. For example, it would be virtually impossible for a court to determine how many miles a particular person drives each year”); and Gilo and Guttel, *Negligence and Insufficient Activity: The Missing Paradigm in Torts*, *supra* note 184 (“courts usually explore the extent to which the defendant–driver took reasonable precautions (level of care). They do not, however, investigate whether the defendant’s mileage (level of activity) corresponds to the socially desirable level.”). We address the issue of activity level separately in Part V.

Alongside the issue of activity levels, this variable might also be normatively difficult to quantify and define. For instance, it could be that the average frequency of driving over a certain time-period would be low, while changing the timeframe would reveal a high average frequency of use. In other words, the variable presents with a problem timeframe definition, and might manifest differently over a short-run versus a long-run review. The timeframe definition problem manifests and multiple settings and forms, and relates to both substantive and evidentiary issues. For instance, even in *United States v. Carroll Towing Co.*, Judge Hand noted that:

“In the case at bar the bargee left at five o’clock in the afternoon of January 3rd, and the flotilla broke away at about two o’clock in the afternoon of the following day, twenty-one hours afterwards. *The bargee had been away all the time*... In such circumstances we hold—and it is all that we do hold—that it was a fair requirement that the Connors Company should have a bargee aboard (unless he had some excuse for his absence), *during the working hours of daylight*.” (*United States v. Carroll Towing Co.*, *supra* note 2, at p. 173; emphasis added).

The above is not an exhaustive list. To the itemized variables, we can add additional safety measures, such as: (i) Automatic Braking; (ii) Adoptive Headlamps; (iii) Reverse Backup Sensors; (iv) Backup Camera; (v) Lane Departure Warning System; (vi) Adaptive Cruise Control; (vii) Tire Pressure Monitoring and Deflation Detection Systems; (viii) Traction Control Systems; (ix) Electronic Stability Control; (x) Electronic Brakeforce Distribution; (xi) Emergency Brake Assistance; (xii) Cornering Brake Control; (xiii) Precrash Systems; (xiv) Laminated Windshields; (xv) Crumple Zone, Anti-Intrusion Bar and Safety Cell Designs; (xvi) Vehicle Color; (xvii) Child Seats, and many others. Furthermore, the risk and expected harm of accidents is (obviously) also contingent upon exogenous variables, beyond the control of the players, such as road conditions, density of traffic, visibility and weather.<sup>200</sup>

Our discussion here is by no means exhaustive, nor is it intended to provide a full account of the working of car accidents. The point to take from here is that the expected harm from car accidents is an outcome of multiple variables, and that no one variable is singlehandedly responsible for determining the overall level of risk. The level of care taken by a driver is a product of different safety measures working together; of combinations or bundles of safety devices, procedures, behaviors and outside settings. Failure to take this diversity of precautions into account is detrimental to any descriptive or normative economic model of negligence. As we shall soon see, the ramifications of such errors can be grave indeed, and manifest in a substantial portion of conventional economic scholarship.

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<sup>200</sup> In some cases, these exogenous settings can be reconceptualized as endogenous variables. That is the case, for instance, when players are allowed to alter their route or time of driving, so as to optimize road conditions, traffic density and visibility. We touch upon this point in a following section.

For more on the overall risk of car accidents see: *Injury Prevention and Control: Motor Vehicle Safety*, CENTER FOR DISEASE CONTROL AND PREVENTION; in URL: [http://www.cdc.gov/motorvehiclesafety/Pedestrian\\_Safety/factsheet.html](http://www.cdc.gov/motorvehiclesafety/Pedestrian_Safety/factsheet.html) and *World Health Organization: World Report on Road Traffic Injury Prevention (2004)* WHO.INT. 2010-12-12; in URL: <http://whqlibdoc.who.int/publications/2004/9241562609.pdf?ua=1>.

Our car accidents example does more, however, than demonstrate the multidimensional structure of negligence puzzles. It also illustrates an important principle—precautionary measures are often substitutional. When that is the case, equal levels of care can be achieved by substituting one precaution, or bundles of precautions, for another, or by increasing the intensity (speed, frequency, quality) of one or more precautions to counter a change in the intensity of others.<sup>201</sup> Within the premise of our example, a combination of driving at 30 miles per hour in a 2003 Mazda 6 without airbags or ABS, in a residential zone while talking on the phone on a rainy day might create the exact same expected harm as driving at 45 miles per hour in a 2013 BMW 3 series convertible with ABS, front, side and knee airbags, electronic stability control and ABS, on a highway, on a bright day and after the driver had a vodka gimlet.<sup>202</sup>

A famous empirical example of such substitution effect goes back to the 1970's, with the early introduction of seatbelts safety legislation. Not surprisingly (at least from an economic perspective), once the use of seatbelts was mandated, the number of car accidents actually—*increased*, and the drop in expected harm incentivized drivers to drive faster. What is interesting in this example for our purposes here is that, according to one study, the overall social harm from car accidents before and after seatbelts were made mandatory was approximately the same. In other words, the anticipated harm resulting from a combination of

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<sup>201</sup> A similar idea is implicit in Cooter and Porat, *Does Risk to Oneself Increase the Care Owed to Others?*, *supra* note 24 (binding together the overall risk reduction resulting from seatbelts and the speed of the car). Note however that Cooter and Porat apply a highly constrained analysis, which considered past actions and omissions as constraints, and do not discuss the normative implications of optimal and suboptimal combinations of precautions along the same isoquant of care, as discussed hereinafter in this part.

<sup>202</sup> To be clear, we make no argument, and one should not be inferred, that the two cases should be adjudicated similarly on a normative level. Nor do we claim that all these variables should be taken into account by a court of law. At this point, the example is only intended to illustrate a descriptive point regarding substitution effects between precautionary bundles.

driving with seatbelts at high speed was roughly equal to the harm from driving slow without seatbelts.<sup>203</sup>

Negligence puzzles are indeed multidimensional and complex. They do not abide by or prescribe to a single dimensionality view. The conventional single dimensionality paradigm therefore fundamentally obscures the true nature and characteristics of most tort problems, and more importantly the normative challenges they present and the optimization processes required to unlock them.<sup>204</sup> As Dari-Mattiacci notes, in a rare recognition of this reality:

“[E]conomic analyses have disregarded the multidimensional nature of precaution and thus have not studied the optimal composition of the bundle of precautionary measures that, if taken, amount to negligent behavior.”<sup>205</sup>

Solving negligence puzzles, *i.e.* setting the legally required level of care or adjudicating whether it has been breached, requires multidimensional frameworks and tools. While this does not mean that courts should always take all possible variables into account, it does mean that lawmakers must think multidimensionally if they aim to bring about efficient deterrence.<sup>206</sup>

We turn our attention now to discuss the basic economic foundations of these frameworks.

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<sup>203</sup> Meaning that after seatbelts were made mandatory, there were more accidents, but fewer driver deaths (but an increase in pedestrian death rates). See Sam Peltzman, *The Effects of Automobile Safety Regulation*, 83 J. POL. ECON. 677 (1975), noted also in Cooter and Porat, *Does Risk to Oneself Increase the Care Owed to Others?*, *supra* note 24, at p. 21; and Steven E. Landsburg, *THE ARMCHAIR ECONOMIST—ECONOMICS AND EVERYDAY LIFE* 3-5 (1993).

<sup>204</sup> The complexities of multidimensionality obviously presents with difficult questions regarding causation, which are outside the scope of this work.

<sup>205</sup> Dari-Mattiacci, *On the Optimal Scope of Negligence*, *supra* note 22 (Developing a multidimensional precaution model, but confining it to the assumptions of orthodox scholarship, such as that the expected accident loss is a decreasing and strictly convex function of each of the parties’ precautionary measures and that functions are assumed to be continuous and continuously differentiable to any desired order. Dari-Mattiacci’s model is focused on providing an economic rationale to the distinction between “care” and “activity level”, rather than modeling the optimal composition of care measures itself).

<sup>206</sup> In some cases, multidimensional thinking would also mean deciding which variables should not be taken into account, and what types of heuristics should be employed. We address these issues hereinafter.

**b. FOUNDATIONS OF ECONOMIC INTERPRETATION: SUPPLY SIDE THEORY AND PRODUCTION FUNCTIONS**

Care is a product. It is the outcome of a multiple-input production function. There is perhaps no better way to conceive and model the precaution or “B-side” of the Hand Formula than using microeconomic production and cost minimization theory. Indeed, negligence is partially a supply side problem, where tortfeasors can be thought of as manufacturers of care, and care levels can be contemplated in terms of precautionary inputs and safety outputs.<sup>207</sup> Oddly enough, existing economic scholarship has largely failed to make this connection, and often ignores the innate intricacies of the supply (or precaution) side of the Hand Formula.<sup>208</sup>

From this point, our review will follow the footsteps of classic microeconomic production theory, and can therefore be discussed with reference to economic literature. Since economic analysis of torts has generally overlooked this aspect of negligence adjudication, and specifically the need to look more deeply into how care is produced, our discussion here is also intended to lay the foundations for more targeted future research projects. Such future projects ought to focus, for instance, on specific markets, technologies or optimization algorithms.<sup>209</sup>

How is microeconomic production theory applicable to negligence law? To easily answer this question, let us take a closer look at the abovementioned car accident example. For

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<sup>207</sup> In this thesis, we generally view precautions as inputs, precaution levels as the level at which of each precaution is taken, care levels outputs as the of taking precautions, which can be represented as isoquant lines of safety and due care as a legal standard denoting the line between liability and exemption from liability. None of these terms should be confused with “activity level”, which denotes a distinction between those factors that are taken into account in negligence analysis and those that are not, as discussed hereinafter in Part V.

<sup>208</sup> Notable exceptions include, Grady, *Response, Another Theory of Insufficient Activity Levels*, *supra* note 163, at p. 31 (reviewing the Gilo-Guttel model referenced in *supra* note 184, while addressing the conventional assumptions of “standard production theory”); and Cooter and Porat, *Lapses of Attention in Medical Malpractice and Road Accidents*, *supra* note 184 (modeling second order precautions using conventional production theory).

<sup>209</sup> For more on cost on optimization calculus and algorithms see Geoffrey A. Jehle and Philip J. Reny *ADVANCED MICROECONOMIC THEORY* 459-501 (2<sup>nd</sup> ed., 2000) (hereinafter: “*Advanced Microeconomic Theory*”).

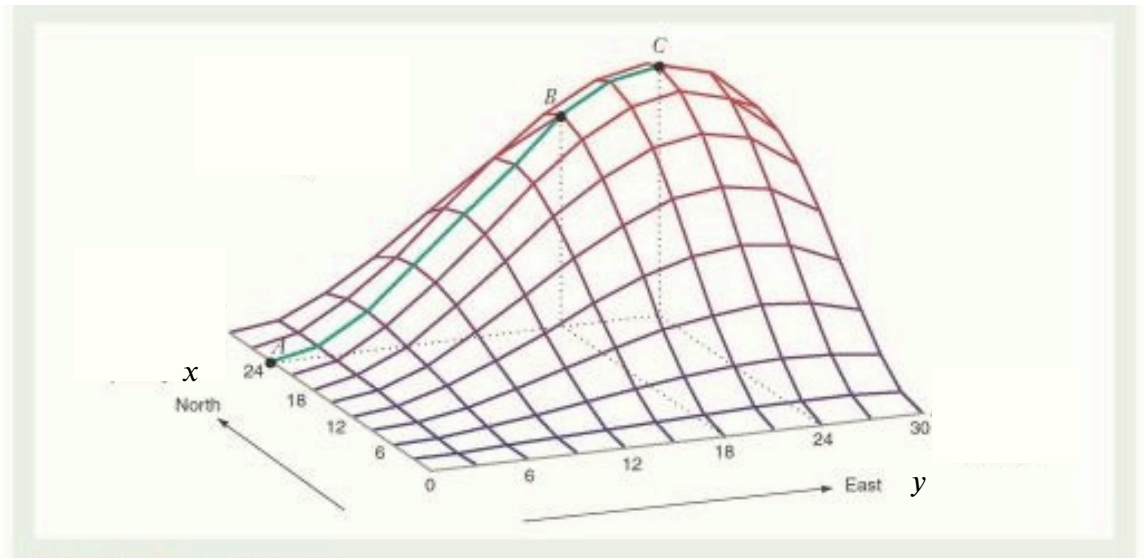
simplicity, we will limit this early discussion and assume that the expected harm from car accidents is a function of only two continuous and likely monotonically convex variables: (i) the speed of the car (precaution  $x$ ), and (ii) the quality or strength of the car brakes (precaution  $y$ ).<sup>210</sup> We can use these two variables broadly to represent the technological possibilities available to prospective tortfeasors, in a similar way to the use of capital and labor in classical economic theory.

Figure IV.1 illustrates the overall safety output from taking the two input variables, using a three-dimensional graph. It therefore shows the total production function, or hill, of care, under certain assumptions soon to be explicated.

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<sup>210</sup> As we have already demonstrated, many precautions can be alternatively conceptualized as continuous or discontinuous. For instance, the quality of the car brakes might in fact mean different types of brakes or the product of different manufacturers. For this example, however, we purposefully use continuous variables, so as to specifically discuss multidimensionality while minimally altering other assumptions of the conventional model.

Figure IV.1: Total Production of Safety Hill<sup>211</sup>



The height of the hill at any point represents the total level of safety produced, as a product of  $x$  and  $y$ . Moving at any direction along the hill changes the elevation of the total production, or overall safety.<sup>212</sup> Starting at any combination of speed and brake quality, we can move northward and decrease the speed of the car,<sup>213</sup> move eastward and increase the quality of brakes or alter both variables and choose a preferred path to traverse.

Notice that we can use the total production function to examine how the overall output would change as a result of alternating only one variable, by holding all other variables constant. Thus, for instance, holding the speed constant at 24 allows us to study the effect of

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<sup>211</sup> Original chart taken from David Besanko and Ronald R. Braeutigam, *MICROECONOMICS* 192 (2<sup>nd</sup> ed., 2005) (hereinafter: “*Microeconomics*”). The economic review in this chapter is largely based on Besanko and Braeutigam, *Microeconomics*, at p. 183-259; Varian *Intermediate Microeconomics – A Modern Approach*, *supra* note 108, at pp. 322-381; and Jehle and Reny, *Advanced Microeconomic Theory*, *supra* note 209, at pp. 117-145.

<sup>212</sup> In this example, each precaution abides by the rule of diminishing marginal returns, and at extreme levels presents with diminishing total returns. For instance, it is not unlikely that reducing the speed of a car past a certain speed on a highway might actually increase the chances of an accident, and that brakes acceding a certain strength would become less safe.

<sup>213</sup> In this example, increasing the level of safety by changing  $x$  would mean reducing the speed of the car.

changes in the quality of brakes on the expected harm at that speed. Path *ABC* illustrates this, by outlining the effect of changes in the quality of the brakes, assuming a speed of 24.

The slope of the *ABC* curve represents the marginal rate of at which care changes as a result of altering brake quality while holding the speed constant at 24. In much the same way, we can slice different cross sections of the total production function to perform a constrained short-run analysis of the efficiency function of any variable. More generally, the cross partial derivative of any particular variable allows us to represent the rate of changes in safety resulting from altering that variable while holding all other variables constant. It therefore allows us to describe the function of one variable under a particular constrained setting.

We should emphasize, especially at this early stage, that the general layout of a production hill is not limited to the shape and figure of the hill we just illustrated. The layout in Figure IV.1 is characteristic to very unique and “clean” settings. For instance, the shape of this total production function is contingent upon the two variables being continuous and monotonically concave,<sup>214</sup> and on a particular type of relationship between them. When that is not the case, the shape of the production function might vary, and might manifest with fluctuating elevations, local gorges and peaks, sudden cliffs and discontinuities, etc.

We have already explored the results of relaxing the notions of continuity and convexity in a single dimensional model in Part III. As this part will soon reveal, relaxing the orthogonality assumption also drastically changes the nature of the production function or hill (which might no longer be a “hill” at all), and with it the processes required to perform

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<sup>214</sup> Meaning, in this example, abiding by the rule of diminishing marginal returns.



negligence cost benefit optimization. At this stage, however, we discuss precautions that are generally uncorrelated, and assume different combinations of precautions are not synergetic.<sup>215</sup>

**c. FOUNDATIONS OF ECONOMIC INTERPRETATION: ISOQUANTS, MARGINAL RATE OF TECHNICAL SUBSTITUTION AND ELASTICITY OF SUBSTITUTION**

Total production functions can also be represented by isoquants (meaning “same quantity” or equal product curves). Isoquant curves mark all combinations of variables that produce a given output or quantity of care. To go back to our above example, isoquant lines will represent the same elevation levels on the production hill, which results from certain combinations of car speed and brake efficiency. Thus, moving along the hill at the same elevation (or isoquant) allows us to outline all combinations of precautions that will produce the same expected harm from car accidents. Figure IV.2 illustrates this idea:

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<sup>215</sup> We discuss interactions and synergetic effects between precautions hereinafter, in Part IV.C.c.

Figure IV.2: Isoquants along a Total Production of Safety Hill<sup>216</sup>

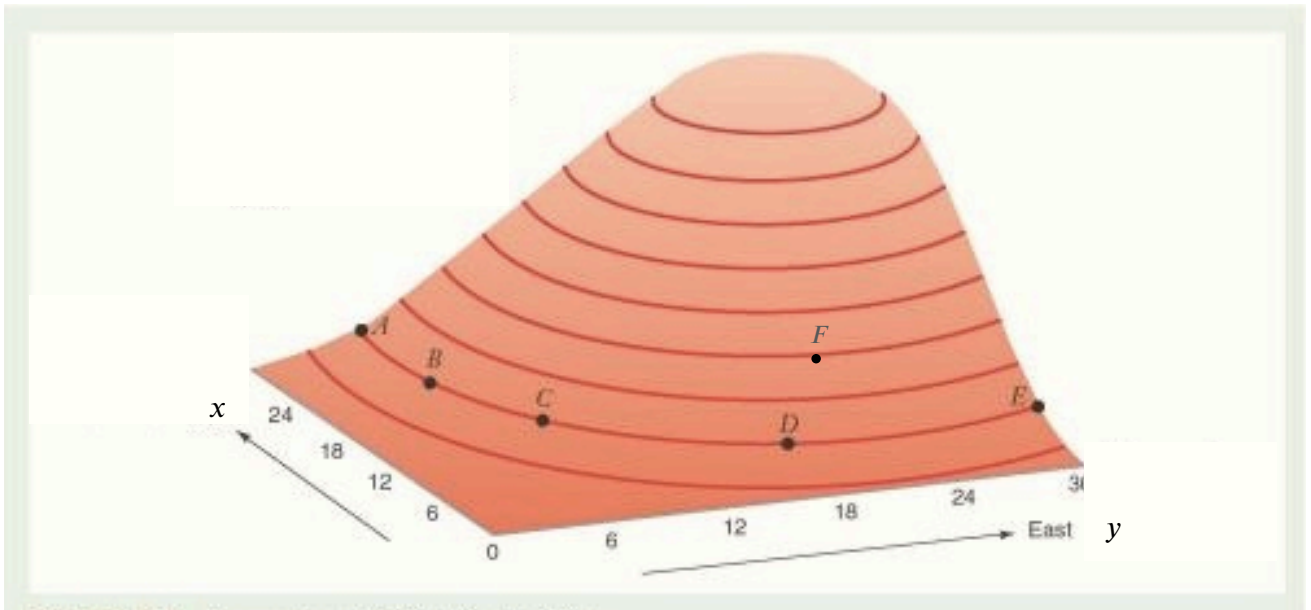


Figure IV.2 is based on the same total production hill shown in Figure IV.1, but adds isoquant lines, signifying identical levels of care. Thus, points *A*, *B*, *C*, *D* and *E* represent identical safety levels, produced by different bundles of *x* and *y*. Much like a topographic map, moving along the *ABCDE* line will not change the elevation or expect harm from car accidents.

Practically speaking, in our example, a prospective tortfeasor can produce a given level of safety by driving fast with excellent brakes, driving slow with low-grade brakes or different combination in a continuum between them. The possibility of such substitutions is demonstrated by the fact that the isoquant lines in Figure IV.2 are downward sloping,<sup>217</sup> meaning that the tortfeasor can trade-off one variable for another. We will discuss alternative

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<sup>216</sup> Original chart taken from Besanko and Braeutigam, *Microeconomics*, *supra* note 211, at p. 194.

<sup>217</sup> For instance, the *ABCDE* segment is downward-sloping when viewed on a two dimensional surface.

cases, where the isoquant lines are upward sloping and backward bending (*i.e.* lead to diminishing total returns) hereinafter, within the context of negative synergies.

The “steepness” of the isoquant lines illustrates the rate at which substitutions between different variables can be achieved. Just as in classic economic theory, we can call this steepness the marginal rate of technical substitution of  $x$  for  $y$ , or  $MRTS_{x,y}$  (and *vice versa*). This term expresses the rate at which  $x$  can be decreased for every increase in  $y$ , holding the level of care constant, or, alternatively, the rate at which  $x$  ought to be increased for every decrease in  $y$ , for the level of care to remain constant. The  $MRTS_{x,y}$  is the (negative) of the slope of the isoquant (*i.e.* the slope of a tangent line to the isoquant) at any particular point.

Convex isoquant lines, such as the  $ABCDE$  line, display a diminishing marginal rate of technical substitution. As we move down along the isoquant line, the marginal rate of technical substitution becomes smaller, and the slope of the isoquant becomes less negative. What this means in practicality is that with every decrease in one variable (for instance, an increase in car speed), more and more of the opposite variable (brake quality) would be required to maintain the same overall level of safety. We further address this quality and its normative implications when discussing different relationships or interactions between variables, specifically in the context of overlapping precautions.

This feature of the marginal rate of technical substitution holds a close relationship to the conventional underlying assumption of convexity of efficiency functions, or diminishing marginal returns of individual precautions. The marginal rate of technical substitution of  $x$  for  $y$  is equal to the ratio of the marginal efficiency of  $x$  to the marginal efficiency of  $y$ . The significance of this ratio is obvious; it allows a player or adjudicator to consider, at any point along the isoquant, whether an additional unit of  $x$  or  $y$  would be more productive, or which of

the variables would have a higher impact on overall safety (of course, the efficient short-run choice would depend on the relative costs of precautions). For instance, assuming individual precautions yield a diminishing marginal return, upgrading a car's brakes would have a stronger effect on safety for a car driving at high speeds than for a car traveling at low speeds, and the marginal rate of technical substitution would be lower at low speeds than for high speeds.

The last term we should define at this stage is elasticity of substitution, usually denoted  $\sigma$ ,  $\sigma \geq 0$ . Elasticity of substitution marks how quickly the marginal rate of technical substitution of  $x$  for  $y$  changes along the isoquant line, or how easily a player can substitute one variable for the other. More specifically, it measures the percentage change in the  $x$  to  $y$  ratio for each percent change in  $MRTS_{x,y}$  along the isoquant. If the elasticity of substitution is close to zero, there is little opportunity to substitute precautions. If the elasticity of substitution is high, the prospects of substituting precautions are also high. Thus, elasticity of substitution can be utilized by prospective tortfeasors or lawmakers to better understand and analyze substitution opportunities in setting the level of due care or devising ways to meet it. Under classic economic assumptions, as one variable is substituted for the second, both the ratio of  $x$  to  $y$  and the marginal rate of technical substitution should fall.

#### **d. FOUNDATIONS OF ECONOMIC INTERPRETATION: COST MINIMIZATION**

##### **PROBLEMS**

Our discussion so far was centered on production functions, and did not address the relevant cost functions and the overall cost-minimization problems derived from considering

production and costs function together. Naturally, however, the aim of efficient negligence rules is to minimize social costs. It might therefore be useful to pause here and note a few important aspects of substitutions in the context of cost-optimization, and the relations between our above discussion and the cost of accidents:

*First*, and this is rather obvious, not all combinations of precautions along a particular isoquant cost the same. The overall cost of care is always contingent on the particular cost functions of the different precautions, and on the levels or quantities of precautions taken.<sup>218</sup> We can therefore use isocosts to denote the sets of combinations of precautions yielding equal costs to the tortfeasor. While isoquants indicate identical quantities of care, isocost signify identical costs.

*Second*, and slightly subtler, not all combinations along a particular isoquant are necessarily cost-efficient, in the sense that their benefit outweighs their cost. It is entirely possible—indeed common—for one combination of precautions along a certain isoquant to be cost-justified, while another combination of precautions along the same isoquant is not. Conversely, it is possible for all combinations of precautions along a specific isoquant to be cost-justified or not cost-justified.

*Third*, when conventional economic assumptions apply, usually only one point along a particular isoquant to be optimal, *i.e.* marks the least expensive combination of precautions required to attain a specific level of care. Under these assumptions, the optimal solution to a defendant's cost-minimization problem occurs at a point where an isoquant is tangent to the isocost line (an interior optima), *i.e.* where the slope of the isocost is equal to the marginal rate of technical substitution, or at corner solutions (where taking only one precautions is optimal).

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<sup>218</sup> Recall that we touched upon precaution cost-functions in Part III.

*Forth*, and more generally, it is likely that only a discrete point (or points) along the entire production function will be socially optimal, *i.e.* minimize the total costs of accidents and maximize social utility. That point represents the optimal level of care and the optimal combination of care measures that will produce it. The legally required standard of care might diverge from this point, and mandate that the defendant take an overall (minimal) care level on a different isoquant, or containing different elements than optimal for the individual defendant.<sup>219</sup> When the legal standard of care states that a defendant must meet at least a specific isoquant of care, and does not derive from an inquiry of a defendant's individual cost functions, technological opportunities and constraints, we can refer to it as exogenous and abstract.

To illustrate these features, consider Figure IV.3, depicting different isoquants along the total production function of care (in red) and isocost line (in blue):

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<sup>219</sup> Many reasons can contribute to such a discrepancy. For instance, the various limitations on cost-benefit analysis in court settings, discussed above, differences between the defendant's individual cost function and those of the "reasonable man" and specific constraints and opportunities, altering the defendant's short-run cost-benefit analysis to depart from an aggregated (long run) *ex-ante* requirement. See also Porat, *Misalignments*, *supra* note 24.

Figure IV.3: Isoquants and Isocosts of Safety Production<sup>220</sup>

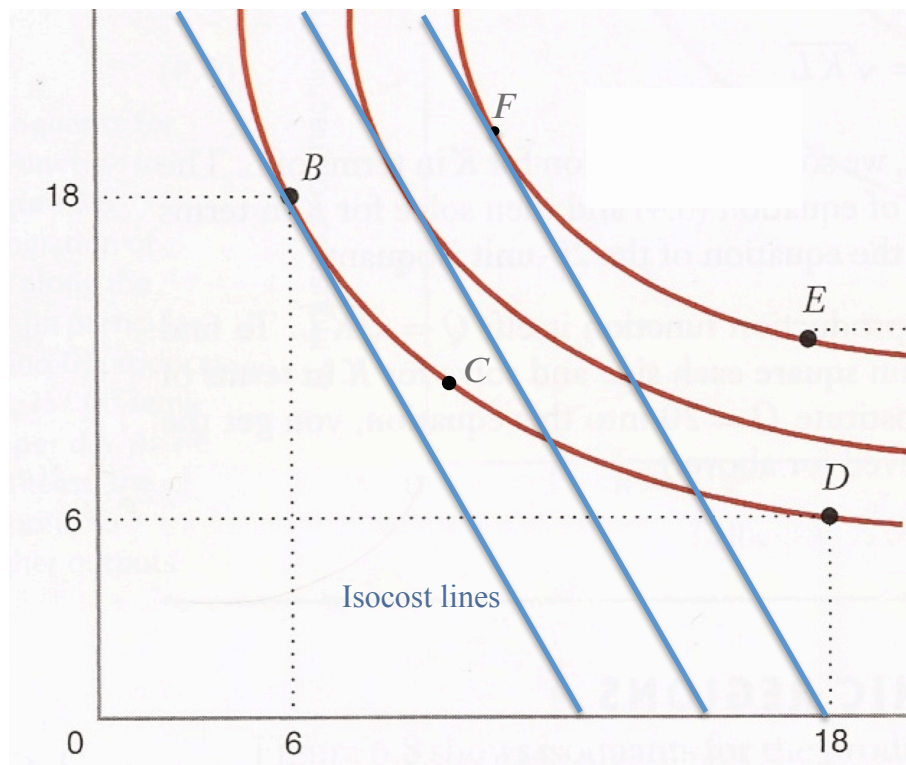


Figure IV. demonstrates the above features we just discussed:

*First*, Points *B*, *C* and *D* represent different combinations of precautions along the same isoquant, resulting in identical levels of expected harm. They do not, however, share the same overall cost. As the isocosts lines make clear, the overall cost of combination *D* is higher than the cost of combination *C*, which in turn is higher than the cost of combination *B*. *Second*, while each point along the *BCD* isoquant represents the maximum level of care a defendant can achieve by using the two precautions at their assigned levels, it is possible for only certain combinations of precautions along the isoquant (for instance points *B* and *C*) to be cost-justified, while others (for instance point *D*) to cost more than the benefit they create (in terms

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<sup>220</sup> Original chart taken from Besanko and Braeutigam, *Microeconomics*, *supra* note 211, at p. 198.

of harm prevention). *Third*, only one combination of precautions along the *BCD* isoquant is cost-optimal, in the sense that it minimizes the cost of precautions for that level of care. That combination is denoted by point *B*, where the marginal rate of technical substitution is tangent to the isocost line. *Forth*, the different cost-optimal combinations of precautions for each isoquant are not necessarily socially optimal. When the level of socially mandated care is not exogenous, it is likely that only discrete points along the entire production function would minimize the overall costs of accidents. For instance, if point *F* in Figure IV.3 represents the socially optimal level of care, point *B* would likely not be socially optimal,<sup>221</sup> even though it minimizes the cost of precaution along the *BCD* isoquant.

The possibility of producing identical levels of care by taking different combinations of precautions, at different costs, along a same isoquant creates a decoupling effect between a defendant's overall investment level and his overall level of care. While the conventional model assumes that a defendant's overall investment level in precaution is synonymous to his overall level of care, that correlation dissolves once the prospect of substitutions between precautions is introduced. For this correlation to hold, the defendant must, at the very least, take only those combinations of precautions that are cost-optimal for each isoquant, and move along the optimal expansion path from one isoquant to the next.<sup>222</sup>

As a result, it is entirely possible for a defendant to overinvest in precautions while falling short of the socially mandated exogenous level of care. For instance, assume that the socially optimal level of care is represented by point *F* on Figure IV.3, and that isoquant *EF* stands at a higher elevation than isoquant *BCD*. The defendant now takes the combination of

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<sup>221</sup> But for the unlikely scenario where combinations *F* and *C* result in identical social costs.

<sup>222</sup> This condition is insufficient against the backdrop of path-dependencies, as address in further length in Part IV with regards to commensurability of multidimensional precautions.



precautions marked *D*. As the isocost lines illustrate, combination *D* is more costly than combination *F*, yet it yields a lower return in terms of safety. Therefore, if isoquant *EF* were to denote an exogenous level of due care, the defendant would fall short of meeting it (as isoquant *BDC* is lower than isoquant *EF*), even though he invested more on care measures than optimally required.

Importantly, Figure IV.3 illustrated that it is entirely possible for a defendant to meet or exceed an exogenous duty of care without taking certain (marginally or *ex-post*) cost-justified precautions. For instance, if the defendant takes the combination of precautions marked *E*, he would (i) meet the exogenous duty of care, as he would take a precaution on the *EF* isoquant; (ii) overinvest in precaution, as the cost of combination *E* is higher than the socially optimal combination *F*; and (iii) might still be able to take additional cost-justified precautions, by moving north from point *E*. We reflect on these issues and the dilemmas they present in detail throughout the normative discussions in Part IV.

**e. ISOQUANTS AND SUBSTITUTIONS IN CASELAW: THE *MIMONI* CASE**

Are the abovementioned economic notions and principles exemplified in caselaw? Are they applicable to real-world settings? The answer to that is clearly in the affirmative. The above are more than theoretical reflections—they reflect law in action.

Substitutable precautionary bundles are omnipresent in negligence law. In various scenarios, prospective tortfeasors may meet or exceed an exogenous and abstract duty of care by employing different combinations of precautions. In various settings, different possible combinations of precautions may converge on the same isoquant of expected harm. As a result,

it is sometimes impossible, unwise or inefficient for lawmakers to require prospective tortfeasors to take specific precautionary measures or specific levels of precautionary means, irrespective of other care measures they might take or have taken.<sup>223</sup> Whether courts conceive the duty of care in abstract or concrete (specific) terms, or endorse a marginal approach, the multidimensional nature of care measures cannot be ignored or circumvented if efficient results are to be reached.<sup>224</sup>

To illustrate these notions, consider the Israeli case of *The Jerusalem Municipality v. Mimoni*. In this case, a 17 year old boy (Plaintiff) traveled with five of his friends to the defendants' riding ranch, which provided "wild" horse riding experiences, and was severely injured when he fell of his horse. The trial court noted that it was the plaintiff's first time riding a horse, that the horse provided to him was "hot tempered," and that the riding instructions delivered were "short and laconic."<sup>225</sup> The court also found that no helmets were issued to the riders, no first aid kit was within reach, no safety instructions were posted on warning signs and that the path elected was treacherous, and included "extremely steep descents, involving stairs...ending with a scramble designed for galloping."<sup>226</sup>

All in all, the court contemplated the following possible precautions-variables: (i) issuing helmets; (ii) posting warning signs; (iii) the length and depth of instruction provided; (iv) the riders' experience; (v) the training and temperament of the horses; (vi) the presence of trained medics and a first aid kit; and (vii) the path's degree of difficulty. Eventually, the

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<sup>223</sup> Our discussion here hints at a hidden divergence between setting the level of care in the abstract (by setting a general investment or safety level) and listing specific measures that must be taken at particular levels. Both approaches, in fact, entail specific advantages and disadvantages, which are addressed hereinafter.

<sup>224</sup> Possible interactions between precautions also play a major part here, and are addressed in the following section.

<sup>225</sup> *Ibid*, at paragraph 2.

<sup>226</sup> *Ibid*, at paragraph 3.

Supreme Court found the defendant negligent, and in a decision issued by Chief Justice Barak on his last day on the bench, held that:

“...[A]n operator and instructor of a riding ranch, which does not insist on his riders using helmets, and takes them riding without a first aid kit which he is trained to use at hand—breaches his duty of care towards the riders. An operator and instructor of a riding ranch, which matches an untrained rider to a hot-tempered horse, at a challenging route, and does not post warning signs that list rules of behavior and riding instructions—breaches his duty of care towards the riders. An operator and instructor of a riding ranch, which does not provide adequate guidance under the circumstances—breaches his duty of care.”<sup>227</sup>

Additionally, the court seemed to have found that failure to provide helmets to riders should be considered a breach of duty in and of itself, noting with regards to riding without helmets that “[t]he expected harm for the victim is high... the costs of preventing the harm, or substantially reducing it, are low, and there is not much public interest in riding without helmets.”<sup>228</sup>

Interestingly, as is evident from the above excerpt, the *Mimoni* court was able to rule only in the negative, holding that a defendant who fails to take *any* of the precautions listed in

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<sup>227</sup> *Ibid*, at paragraph 5.

<sup>228</sup> *Ibid*, at paragraphs 6-7. The section reads:

“...[W]e did not overlook the expert opinion provided by [the defendant]... according to which it is not customary to wear helmets during Western open-field riding, which is the kind of riding pertinent to this case....”

In evaluating the reasonableness of a particular action, ‘the court ought to balance the victim’s interest in personal safety, and the injurer’s interest in freedom of action, in light of the public interest in the continuation or secession of that particular activity.’... At times, adjudicating the reasonableness of an action is hard. That is the case, for instance, when the cost (in terms of utility) of taking precautions is high, and the expected harm from the activity is also high. However, in this case, the balancing act is easy for us. The expected harm for the victim is high. It might, in some cases, present a risk to life itself. On the other hand, the costs of preventing the harm, or substantially reducing it, are low, and there is not much public interest in riding without helmets. In this state of affairs, we find it easy to rule that the behavior that caused the harm was unreasonable...”

three separate *bundles* of precautions would be found in breach of duty. Thus, defendants would be found negligent if they: (i) send their customers riding without helmets or a first aid kit and they are trained to use; or (ii) pair an untrained rider with a hot-tempered horse on a challenging route without posting warning signs; or (iii) fail to provide adequate guidance “under the circumstances.”

With the possible exception of helmets, discussed in a separate passage, no single precaution was found by the *Mimoni* court to be categorically necessary or sufficient to meet the duty of care. The multidimensional and substitutable nature of the settings rendered Chief Justice Barak unable to set a comprehensive (aggregated) list of precautions that future tortfeasors would have to apply in order to meet the standard of care, or set an overall duty of care in the abstract.<sup>229</sup> The same multidimensional feature rendered the court unable to point to any single (marginal) precaution, with the possible exception of helmets, defendants must always take in order to abide by the duty of care.

The *Mimoni* Case therefore illustrates the idea that precautions are characteristically multidimensional and substitutable: different variables are frequently intertwined and interchangeable in ways that necessitate courts to study and evaluate the nature of negligence puzzles far more sincerely than assumed by conventional models. More technically, *Mimoni* illustrates that different combinations of precautions can be on the same isoquant line, and there might be multiple alternative ways to meet an exogenous and abstract duty of care. Riding a hot-tempered horse might be reasonable when the rider is experienced and the route is simple to traverse. Riding on a challenging path might be reasonable after detailed instructions are provided, the riders are well trained and medical equipment is nearby, and so forth. To be

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<sup>229</sup> We have already explored this feature when discussing the aggregated approach. See above, in Part I.B.a.

effective and convey prescriptive and precedential meaning, a court must often resort to discussing bundles of precautions, as the *Mimoni* court chose to do.

The coined phrase “under the circumstances”—so often used in caselaw<sup>230</sup>—is also a strong “tell” of a court’s inability to rule on individual precautions, irrespective of others. The *Mimoni* court could only hold that instructions must be adequate “under the circumstances,” because it could not prescribe an *a priori* level of instruction that would not be contingent upon other precautions and settings.<sup>231</sup> Similarly, in *United States v. Carroll Towing Co.*, the court resorted to find the defendant in breach of duty “[i]n such circumstances,” noting “there is no general rule to determine when the absence of a bargee or other attendant will make the owner of the barge liable for injuries to other vessels if she breaks away from her mooring.”<sup>232</sup> Therefore, through our perspective here, “under the circumstances” should simply be regarded as code for a singular piece of a puzzle, a non-demonstrative variable within a multivariable framework. For multidimensional frameworks, definitive duties pertaining only to specific precautions are difficult, if not impossible to determine.

#### **f. NORMATIVE REFLECTIONS: EX-ANTE VERSUS EX-POST OPTIMIZATION**

Multidimensional settings also bring a distinctive and chronic normative difficulty to surface, which has been generally ignored in tort scholarship. Due to the substitutable quality of different precautions, it is entirely possible—indeed prevalent—for a defendant to meet or

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<sup>230</sup> For a canonical example see *Brown v. Kendall*, *supra* note 10 (“In using this term, ordinary care, it may be proper to state, that what constitutes ordinary care will vary with the circumstances of the cases.”).

<sup>231</sup> Naturally, the term “circumstances” also includes the risks involved. Note, however, that whether something is considered an exogenous risk or a variable is not always predetermined, and most often reflects policy considerations.

<sup>232</sup> *United States v. Carroll Towing Co.*, *supra* note 2, at p. 173.

exceed the socially required level of overall safety while failing to take a specific cost-justified (marginal) precaution.<sup>233</sup> To use a simple example, a tortfeasor might take one precaution at a higher than otherwise optimal level (for instance, in *Mimoni*, post more warning and guidance signs) and offset the effect of taking another precaution at a suboptimal level (for instance, providing a shorter than optimal face-to-face instruction).<sup>234</sup> The normative question can therefore be phrased as follows: should a defendant be found negligent if he fails to take a marginally cost-justified precaution on the one hand, but meets or exceeds the otherwise socially required (optimal) level of care on the other?<sup>235</sup>

In *Mimoni*, Chief Justice Barak provided two ambiguous and to some extent contradictory (or arguably complimentary) answers to this question.<sup>236</sup> One ostensible take away from this case is that failure to issue helmets to riders *always* constitutes negligence, irrespective of other variables. Therefore, helmets are always regarded as marginally cost-justified, notwithstanding any other precautions already taken, and must always be issued regardless of the overall expected harm created by the defendant. Alternatively, *Mimoni* implies that defendants can meet the duty of care by employing *alternative* combinations of precautions, and offset suboptimal variables through increasing the level of others. This suggests that no single precaution (other than perhaps helmets) can be considered marginally

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<sup>233</sup> For our purposes here, assume that the marginal precaution not-taken is cost-justified after other precautions have already been taken.

<sup>234</sup> Assume that even after this tradeoff, additional instructions are marginally cost-justified. As we will soon clarify, the *ex-ante* socially optimal number of signs is a result of a multidimensional optimization process, and cannot be performed separately for each variable. Notice also that the resulting composition of precautions from this offset might not be globally optimal in terms of costs, but might reduce the overall expected harm by the same extent nonetheless. Finally, sunk costs and past taken actions sometimes render *ex-ante* suboptimal combinations of precautions economically justified from an *ex-post* perspective.

<sup>235</sup> We assume, for purposes of our discussion here, that the duty of care is exogenous, and simply denotes the minimal expected harm deemed socially acceptable and cost-justified while engaging in a certain activity.

<sup>236</sup> The issue of substitution was not explicitly pleaded in *Mimoni*, but is nonetheless pivotal, I believe, to the understanding of this case.

demonstrative in adjudicating negligence. We revisit the *Mimoni* case hereinafter, in the context of interacting precautions.<sup>237</sup>

Was *Mimoni* decided correctly? Is there a more definitive and rigorous answer to this normative dilemma? Recall that we have already discussed a similar notional difficulty in Part III, section III.E.b., in the context of non-convex single dimensional social costs functions. There, we contemplated whether, and if so when, it would be justified to require a defendant who has taken precautions beyond the socially optimal level of care, to “go the extra mile” and take an additional marginally cost-justified precaution. Our answer both there and here is that this dilemma has no easy answer, and reflects an innate and unsolvable tension within negligence law:

On the one hand, finding a defendant negligent for failing to take additional cost-justified precautions creates efficient short-run incentives for the defendant. After precautions have already been taken, conventional economic wisdom would consider them sunk costs, and exclude them from future cost-benefit analysis. When existing conditions are viewed as constraints, the socially efficient policy is to require tortfeasors to take *ex-post* marginally cost-justified (bundles of) precautions, regardless of their past-taken actions. Indeed, if a defendant had an opportunity to take a cost-beneficial precaution at the time of the accident, and did not seize that opportunity, it would seem logical, even commonsensical, to consider him negligent. Put figuratively, if a driver is driving at a higher than optimal speed, why should we care that he installed superior brakes six months before?<sup>238</sup>

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<sup>237</sup> This result can also be explained through the workings of overlapping precautions, as explained and discussed in Part IV.C.C.ii.

<sup>238</sup> Assume for this example that no statutory speed limit is set, and that driving at a slower speed than actually driven is *ex-post* cost justified. Assume also that the aggregated risk resulting from the combination of superior brakes and high speed is on the same isoquant as the overall risk resulting from the combination of regular brakes and the slower

On the other hand, applying a constrained marginal analysis in a foreseeable manner might create inefficient long-run incentives for the defendant, and go against common notions of justice. From a justice perspective, as we have already observed in Part III, a constrained approach would make it possible for one defendant to take *more* precautions than another, creating an overall reduced risk of harm, and yet be found liable for not taking a marginally cost-justified precaution, while the other defendant is exempt from liability. Furthermore, it is also possible for precautions to become marginally cost-justified solely because the defendant has exceeded the socially optimal level of care by his past actions, further exacerbating the apparent injustice of placing liability on the defendant in such cases.

From an efficiency perspective, a purely *ex-post* approach might distort the defendant's incentive framework by creating an unwanted deterrence against taking extra precautions, coupled with a strategic incentive to detrimentally exploit judicial "memoryless" or path-dependent decision-making algorithms.<sup>239</sup> Finally, from the perspective of injured parties, an *ex-post* approach might result in compensating a plaintiff who was subjected to less of a risk than an uncompensated plaintiff.<sup>240</sup> Such a policy would therefore have some plaintiffs enjoy the fruits of a marginal analysis, in a manner that undermines the fabric of our common understanding of corrective justice and Aristotelian equality.<sup>241</sup> If bilateral precautions are assumed, such a policy might also distort the *ex-ante* incentive framework facing plaintiffs.<sup>242</sup>

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speed.

<sup>239</sup> We further discuss these distorted incentives hereinafter.

<sup>240</sup> Actually compensation would also depend on causation and the manner at which damages are calculated, both issues beyond the scope of this work.

<sup>241</sup> On the foundations of corrective justice, see E. J. Weinrib, *THE IDEA OF PRIVATE LAW* (Cambridge, Mass., 1995). See also Jules Coleman, *THE PRACTICE OF PRINCIPLE: IN DEFENSE OF A PRAGMATIST APPROACH TO LEGAL THEORY* 3-54 (Oxford, 2001).

<sup>242</sup> As already noted, our discussion in this thesis is limited to unilateral precautions, and posits that tort scholarship has ignored important difficulties associated with the conventional modeling of unilateral precautions. On



Lastly, the possibility of substitutions between different (bundles of) precautions might create interesting challenges in the context of joint risk precautions<sup>243</sup> and self-risk. As Cooter and Porat eloquently argue, and the RESTATEMENT (THIRD) OF TORTS acknowledged, the application of the Hand Formula might be flawed if the self-risk to the defendant is not taken into account.<sup>244</sup> For instance, in some cases, the “risk-side” of the Hand Formula should include not only the risks to others created by driving, but also the possible risks to the driver himself. Thus, if a driver was unable to buckle his seatbelt, he ought to be required to drive slower as a result, and not imposing such a duty on him might lead to inefficient deterrence and possibly avoidable harm to others.

Yet, when the possibility of substituting some precautions for others is recognized, and the duty of care is thought of as exogenous and abstract, inefficient incentives on the defendant might result. For instance, assume that a driver has two alternatives: (i) reduce the risk to others by 30 at a cost of 10; or (ii) take a joint risk precaution that reduces the risk to others by 20 and the risk to self by 10, at an overall cost of 15. While the first alternative is socially optimal (as it results in social gain of 20 compared to 15 in the second option), setting the duty of care in the abstract would induce the driver to choose the suboptimal second option, as it would minimize his overall expected expenditure and loss. More generally, if the duty of care is set from an *ex-ante* perspective in general and abstract terms, and self-risk is “part of the game,” a rational defendant might inefficiently minimize self-risk and shift his composition of

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the prolific writing regarding bilateral precautions, and the possible inefficient incentives manifested there, see also *supra* note 95.

<sup>243</sup> Meaning precautions that reduce both the risk to others and the self-risk to the defendant.

<sup>244</sup> Cooter and Porat, *Does Risk to Oneself Increase the Care Owed to Others?*, *supra* note 24. See also אריאל פורת, רשלנות וסיכנון העצמי של המזיק, בשולי פסק דין ע"א 3510/99 ולעס נ' אגד אגודה שיתופית לתחבורה בישראל, עיוני משפט כו(1) 321 (2002).

care measures to include more joint risk precautions, at the expense of third parties. For risk averse defendants,<sup>245</sup> that possibility is more than likely, and might exacerbate incentives to take inefficient (rather than simply suboptimal) precautions. Additionally, once a defendant has overinvested in joint care measures, he might be induced to inefficiently decrease his investment in non-verifiable precautions. For instance, he might be tempted to inefficiently search of an object in a car with an automatic braking system and anti-intrusion bar, increasing the risk to pedestrians.

**g. NORMATIVE REFLECTIONS: VARIABLE SELECTION**

The above tension between short and long-run (or constrained and unconstrained) optimization is also closely related to the challenge of variable selection.<sup>246</sup> Negligence law generally lacks an overarching methodology to distinguish between variables and constraints, *i.e.* adjudicate when a particular action, behavior or omission should be considered a “precaution” (variable) or an exogenous setting. Such a methodology is, however—crucial. Anderson accurately captured this lapse by noting:

“[T]he economic analysis of tort law has yet to satisfactorily answer a critical threshold question: which of the many inputs that leads to an accident should be included in a court’s liability analysis?”<sup>247</sup>

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<sup>245</sup> For instance, with regards to their bodily integrity.

<sup>246</sup> For a unique piece on variable selection in negligence law see Anderson, *The Missing Theory of Variable Selection*, *supra* note 22. See also Feldman and Kim, *The Hand Rule and United States v. Carol Towing Co. Reconsidered*, *supra* note 20. For a related discussion regarding the distinction between activity level and care measure see Part V.F.

<sup>247</sup> Anderson, *ibid.*, at pp. 255, 282 (similarly stating, “Surprisingly, there has been relatively little effort to address the general issue of accident input inclusion in the literature” and “Without an answer to this question, the economic analysis of tort law yields indeterminate prescriptions.”). See also Dari-Mattiacci, *On the Optimal Scope of Negligence*, *supra* note 22.

To make things concrete, consider the *gratis dictum* from the famous case of *Brown v. Kendall*: “A man, who should have occasion to discharge a gun, on an open and extensive marsh, or in a forest, would be required to use less circumspection and care, than if he were to do the same thing in an inhabited town, village, or city.”<sup>248</sup> When should a man’s surroundings be considered exogenous setting, and when should they be viewed as a variable under his control? Similarly, to go back to the facts of *Mimoni*, reflect on a rider’s experience, the temperament of a horse or a riding path’s degree of difficulty—should they be considered as variables under the control of the tortfeasor, or should they be regarded constraints in the optimization process? Is a car’s model or type of airbags an exogenous risk to balance, or a precaution to be efficiently adjusted?

This deconstructive distinction bears great practical importance, and manifests in almost every negligence case.<sup>249</sup> Sadly, the difficulties associated with making this determination cannot be universally and conclusively resolved by answering any single question, such as whether sufficient time has pass since an action has been taken (for something to transition from an exogenous to endogenous variable), is a past action changeable or what are the costs of changing it. To elucidate the impact of variable selection in real world settings, consider a simple example loosely based on the facts of *Mimoni*:

A global *ex-ante* optimal combination of precautions consists of, among others, posting 4 signs and providing a 20 minute instruction session. A riding ranch posted 6 signs in the past, instead of only 4, each including rules of behavior usually delivered during instruction.

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<sup>248</sup> *Brown v. Kendall*, *supra* note 10.

<sup>249</sup> For yet another famous case tacitly contemplating this issue, see Justice Cardozo’s opinion in *Adams v. Bullock*, 227 N.Y. 208, 125 N.E. 93 (1919) (*de-facto* considering whether an overhead trolley was an exogenous circumstance under the defendant’s franchise, or was it an endogenous risk, noting that “neither [the defendant’s] power nor its duty to make the change [from overhead to underground wires] is shown”).

An accident occurs the following month. What should be the standard of care at the time of the accident?

One possible answer is to consider the 6 signs posted by the ranch as constraints, and apply an *ex-post* cost benefit analysis. In this case, it could be that only a 15-minute face-to-face instruction session (rather than 20) would be sufficient to meet the duty of care. The other option is to consider the number of signs as a variable. In that case, the judicial ruling would depend on the optimization process applied by the court, and be contingent on questions such as: are variables optimized separately or in conjunction? Are individual variables optimized assuming all other variables are taken at the *ex-ante* socially optimal level, or does the court measure only of the overall safety outcome? We address these issues in further depth hereinafter, in Part V. For now, it will suffice to say that each choice entails unique gains and shortcomings, once again reflecting conflicting values and an innate tension between constrained and unconstrained optimization in torts.

Notice also that the distinction between variables and constraints might also affect other legal aspects of negligence adjudication. For instance, while endogenous variables are subject to the statute of limitations and the statute of repose—exogenous settings are not. Therefore, when something is classified as an endogenous variable, the plaintiff is able to argue breach of duty with regards to it, but such a claim might be subject to the statute of limitations. Thus, for instance, if a defendant has made a suboptimal choice in the far past,<sup>250</sup> and additional precautions cannot be presently added, the defendant would be exempted from liability for his suboptimal past choice in light of the statute of limitations, and no cause would be found for placing blame on him in the present. Alternatively, when a past action or omission is classified

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<sup>250</sup> *i.e.* a superior cost-justified precaution could have been taken instead of the one actually taken.

as exogenous, the plaintiff will not be able to claim negligence with regards to it, and the defendant might not be able to invoke the statute of limitations with regards to it.<sup>251</sup> The defendant in this case would be subject to a constrained analysis, which might in some cases prove detrimental to his position. For example, if the defendant has overinvested in precautions in the far past, and as a result his current setting allows for an additional precaution to be efficiently added, he might be found in breach of duty.

#### **h. NORMATIVE REFLECTIONS: RULES VERSUS STANDARDS REGULATION**

Our discussion above also reveals an additional hidden dilemma pertaining to negligence standards, which can be defined as follows: to what extent should courts prescribe specific precautionary measures, and to what extent should they set the minimal level of care in the abstract. Assuming the expected harm from an activity is exogenous and known,<sup>252</sup> when should negligence law regulate parties' behavior by directly stipulating specific precautions that must be taken, not-taken or be taken at particular levels, and when should law provide room for the market to decide how to meet the duty of care?

The dilemma in this case resonates with a known divide between rules and standards in the context of regulation.<sup>253</sup> On the one hand, directly prescribing specific and concrete rules of behavior introduces certainty to the market, reduces judicial costs and enables efficient

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<sup>251</sup> The actual application of the statutes of limitations in negligence substantially differs between jurisdictions, based on such issues as whether the time the damages accrued, the breach of duty occurred or any of them or the causation between them becomes known or reasonably accessible to the plaintiff.

<sup>252</sup> This assumption is not trivial, and we use it for it for limited purposes here.

<sup>253</sup> For a related discussion of the merits of regulation versus tort law see Steven Shavell, *Liability for Harm Versus Regulation of Safety*, 13 J. LEGAL STUD. 357 (1984); Donald Wittman, *Prior Regulation Versus Post Liability: The Choice Between Input and Output Monitoring*, 6 J. OF LEGAL STUD. 193 (1977); and Susan Rose-Ackerman, *Regulation and the Law of Torts*, 81 AM. ECON. REV. 54 (1991). See also Issacharoff and Witt, *The Inevitability of Aggregate Settlement*, *supra* note 34, at pp. 1578-1579.

enforcement. It may also lead to efficient market standardization, induce technological development to meet said standardization and reduce the costs of individual information seeking and of performing cost-benefit analyses.

On the other hand, regulating through prescribing abstract duties allows for greater flexibility in judicial decision-making, is better adapted to adjudication in an environment of technological changes and provides room for judges to tailor judgments to specific conditions. Importantly, regulating in general terms recognizes the market's superior ability to take individual cost functions, efficiency functions and constraints into account, and allows parties to choose between substitutable precautions and alternative bundles of precautions.<sup>254</sup> Moreover, and directly related to this thesis, it can grant courts more leeway to address inefficient strategic behaviors taken by players.

Finally, and this is indeed a pivotal part of our discussion, the above difficulties might render the current formulation of the marginal approach naïve at best, and harmful at worst. The marginal approach's reputation as a golden standard in economic scholarship largely results from an equivalency assumption, that routinely applying the marginal approach will lead to socially optimal solutions, identical to the ones reached by an aggregated analysis. Yet, as we have just illustrated, the marginal approach cannot guarantee socially optimal results against the backdrop of multidimensional and substitutable precautions. At the very least, therefore, one should cast doubt on the applicability of the marginal approach to all settings, and its ability to generate efficient incentives in myriad scenarios. Our next section further explores why and how.

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<sup>254</sup> There is a middle ground between the two. For instance, a court may consider some precautions substitutable (such as in our above example, providing face-to-face instructions and warning signs) while declining to consider others as substitutable.

## C. THE ORTHOGONALITY AND PREDETERMINACY ASSUMPTION

### a. GENERAL FRAMEWORK AND TAXONOMY

Our discussion so far neglected to address a crucial element. Simply adopting a multidimensional view of the precaution side of the Hand Formula is not enough. Once precautions are understood to be multidimensional, the *relationship* between different precautions (or dimensions) must also be explored.

Under the conventional model, precautions are assumed to be single dimensional. To the extent a variety of precautions is recognized (for instance, when they are commensurated along a single  $x$  axis),<sup>255</sup> the conventional model tacitly assumes that precautions are orthogonal, and that the (i) possible scope of precautions; (ii) overall efficiency of care; and (iii) marginal efficiency of each precaution, are not path-dependent.<sup>256</sup> When that is the case, precautions can be ranked and sorted in perfect order based on predetermined qualities, and represented as if they were of one type or dimension. Our above discussion, however, never made any of these assumptions.

In reality, taking one precaution almost always impacts the marginal efficiency of others. Precautions are correlated. Their marginal efficiency is contingent on one another.<sup>257</sup>

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<sup>255</sup> As already noted, that is the case when a general “precaution level” or “investment in precautions level” is modeled.

<sup>256</sup> As we shall see, these assumptions are critical for the orthodox application of the marginal approach and the conventional model. Interestingly, Grady’s original analysis of the *Hendricks* Case also hides this notion (see Grady, *Discontinuities and Information Burdens*, *supra* note 1 and Table 1 above). To see this, notice that the precautions already taken by the defendant in *Hendricks* were termed “actual” by Grady, and considered sunk costs and preexisting constraints. It is possible, however, that that marginal efficiency of the fence, barricades, lifeguards and signs would have been different if the prior (“actual”) precautions were not taken, or even that the long-run social optimum would have been different under if preexisting precautions were not viewed as constraints.

<sup>257</sup> Though not as common, it is also possible for cost-functions to be codependent. This is the case when the cost of taking one precaution is linked to the level of other precautions. The resulting effects are similar to various effects of interactions between precautions discussed hereinafter. For a related example in the nuisance context, see Guttel, *The (Hidden) Risk of Opportunistic Precautions*, *supra* note 39, at n. 78 (discussing *Penland b. Redwood Sanitary*

Once a particular precaution is taken, it inevitably affects the efficiency, desirability and normative necessity of taking an additional (marginal) precaution. When that is the case, and it nearly always is, the principal question of negligence law ought not be “what is the optimal level of different precautions?” but rather “what is the optimal *combination* of different precautions?”<sup>258</sup>

Indeed, the optimal level of each precaution within a multidimensional framework is rarely axiomatic or independently attainable, and cannot be predetermined irrespective of other precautions. Predeterminacy is a quality found only in the rare occasions where the marginal efficiency of a precaution does not change with any and all alterations of other precautions. More technically, it requires that the cross partial derivative of a certain variable be identical under any and all conditions and under all degrees of freedom employed in the analysis.<sup>259</sup> The conventional predeterminacy assumption, which lays the foundations for the constrained marginal approach by undertaking that the marginal efficiency of precautions is not path-dependent—is therefore hardly ever factually true.

Interactions between precautions are conceivably the most prevalent reason why so many tort cases resist easily applicable marginal solutions, and perhaps the principal hurdle to a constrained optimization of real-life tort puzzles. Understanding the different types and ways precautions may interact is therefore normatively and practically imperative. Yet, faced with

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*Sewer Service District*, 965 P.2d 433 (Or. Ct. App. 1998), where the court took notice of defendant’s past strategic investment aimed to augment prevention costs, and subsequently ruled for the plaintiff despite short-run considerations to the contrary).

<sup>258</sup> This conclusion is generally true for both constrained and unconstrained analyses method.

<sup>259</sup> Notice that it is insufficient for an efficiency function of one variable to be unaffected by isolated changes in other variables. For the predeterminacy assumption to hold, the efficiency function of any variable must not be affected by changes in any and all combinations of all other variables. It is possible for the marginal efficiency of a particular variable (*x*) to be unaffected by changes in variable *y* and unaffected by changes in variable *z*, yet react to cumulative changes in *y* and *z*.



this challenge, legal theory has thus far failed to develop an adequate vocabulary to describe and categorize such interactions. Indeed, it never truly conceded they exist.<sup>260</sup>

The dissertation suggests such a taxonomy of relationships between variables on the “B-side” of the Hand Formula, and distinguishes between the following:

- (i) Independent (orthogonal or uncorrelated) precautions: precautions with marginal efficiency functions that are unaffected by changes in the other precautions. Perfectly substitutive precautions, discussed hereinafter, are a subset of this category, where the elasticity of substitution is infinite ( $\sigma = \infty$ );
- (ii) Complementary precautions: precautions that require a fixed ratio between them for each care level, and do not allow for substitutions ( $\sigma = 0$ );
- (iii) Mutually exclusive precautions: precautions that exclude one another, so that taking one precaution prevents the application of another. Exclusion might also exhibit only in certain ranges or be contingent on exogenous conditions; and
- (iv) Interacting precautions, which are further divided between:
  - a. Negatively synergetic interactions (precautions): a type of interaction between precautions that results in a decrease in total returns; *i.e.* where the total product of safety for a particular combination of precautions is smaller than that of a subset of the same combination.
  - b. Overlapping interactions (precautions): a type of interaction between precautions that results in a reduction of marginal returns, *i.e.* where the total product of safety for a particular combination of precautions is smaller than

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<sup>260</sup> The conventional literature extensively deliberates, however, interacting precautions in the context of multi-player games and bilateral settings. On that, see *supra* note 95.

the aggregated benefits of the same precautions, had they been taken individually; and

- c. Positively synergic interactions (precautions): a type of interaction between precautions that results in an increase of marginal returns, *i.e.* where the total product of safety of a particular combination of precautions is higher than the aggregated benefits of its subparts, had they been taken individually;

When the world is seen, as it is—a convoluted tapestry of multidimensional interactions—negligence law presents new and unanticipated challenges. For most of these challenges, defaulting to a constrained and myopic marginal analysis is ill advised and frequently harmful. More specifically, each type of interaction might lead to different inefficiencies, suboptimal results and strategic behaviors as a consequence of the misguided application of the marginal approach. The following sections address these consequences in detail, and provide further examples.

**b. INDEPENDENT, COMPLEMENTARY AND MUTUALLY EXCLUSIVE PRECAUTIONS**

The first three types of relationships between precautions—*independent, complementary and mutually exclusive*—can be discussed here in brief, as they are not all that frequent, and present with few normative difficulties compared to other types of interactions. The effects and workings of these relationships are similar to the results derived by the conventional model, or can be classified as special cases within our following discussion.

**i. INDEPENDENT PRECAUTIONS**

Independent precautions, which can also be termed orthogonal or uncorrelated precautions, are characterized by marginal efficiency functions that are not affected by changes in the level of other precautions. To give a concrete example, the marginal efficiency of knee airbags is probably unaffected by the installation of head or side airbags.<sup>261</sup> The individual efficiency function of each precaution can be of any type, and may display decreasing, increasing, constant or fluctuating marginal returns—so long as that function is unaffected by changes in the other variables. Under the conventional model, precautions are assumed to be convex and independent, which allows for the predeterminacy assumption.

Orthogonal precautions can be substitutable, in the sense that increasing the level of one precaution can offset a decrease in the level of the other, and display altering technical rates of marginal substitution (again so long as the marginal efficiency of each precaution is not affected by another). Furthermore, a particular precaution can be orthogonal with respect to one precaution, and interact with (or be affected by) changes in another precaution. For example, while the marginal efficiency of knee airbags might not be affected by the installation of other types of airbags, it might be very responsive to changes in the speed of the car.

Perfect substitutions are a special case of independent precautions. Perfectly substitutable precautions are characterized by a constant marginal rate of technical substitution of one precaution for another, and therefore result in linear downward-sloping isoquant lines (since the  $MRTS_{X,Y}$  reflects the slope of the isoquant). When they occur, the marginal

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<sup>261</sup> For instance, if we assume that any particular accident can thrust the driver in either a front-and-upward trajectory (towards the windshield, where the front airbag is located), a front-and-downward trajectory (towards the pedals, where the knee airbag is located) or a side trajectory (towards the door, where the side airbag is located). In this example, the precautions also do not seem to be substitutable.

efficiency of each precaution is not affected by changes in other precautions. Because the marginal rate of technical substitution does not change along the isoquant, the elasticity of substitution for perfect substitutions is infinite ( $\sigma = \infty$ ),<sup>262</sup> so that different inputs (precautions) are infinitely (perfectly) substitutable.

## ii. COMPLEMENTARY PRECAUTIONS

Complementary precautions illustrate a dramatically different case than perfect substitutions, and offer no possibility of substitution. To give a concrete example, medical personnel and first aid kits, mentioned in *Mimoni*, can be considered complementary, if we assume that only medics can work first aid kits, but that they cannot offer medical help without them (meaning that a 1:1 ratio between first aid kits and medics is required). Similarly, as each horse rider requires exactly one helmet and two elbow pads, a riding ranch would not be able to substitute helmets for elbow pads. The ratio between the two precautions would have to be constant (in this case, 1:2), and additional helmets or elbow pads beyond that ratio would not create any additional care. Complementary precautions exhibit a fixed-proportion production function, where the overall production of safety is set by  $Min(ax, by)$ .<sup>263</sup>

For complementary precautions, isoquant lines are parallel to the  $x$  and  $y$  axes, with the “knee” or corner of the isoquants marking the optimal (fixed) ratio of precautions. The elasticity of substitution for complementary precautions is zero ( $\sigma = 0$ ), because the marginal rate of technical substitution of  $x$  for  $y$  changes from  $\infty$  to 0 at the corner (“knee”) of the

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<sup>262</sup> Because the percentage of change in  $MRTS_{x,S}$  is in the denominator of the definition of elasticity of substitution.

<sup>263</sup> Where  $x$  and  $y$  are the precaution-variables and  $a$  and  $b$  are positive constants.

isoquant, and the tortfeasor has no flexibility to substitute amongst precautions. Complementary precautions may analytically be viewed as a special case of positively synergetic precautions, as (at certain rations) an increase in the level of one precaution would positively affect the marginal efficiency of the other. We discuss positive synergies in a subsequent section.

### iii. MUTUALLY EXCLUSIVE PRECAUTIONS

Mutually exclusive precautions, our final category here, are characterized by mutual rejection, where taking one precaution precludes the tortfeasor from taking another.<sup>264</sup> For instance, if different kinds of wheel-tiers are conceived as different types of precautions (rather than one vector precaution), then once a particular brand and making of tier is chosen, it precludes all other kinds of tiers from being installed on the same car.

Analytically, mutually exclusive precautions can be considered a special case of overlapping precautions, where taking one precaution reduces the marginal efficiency of the other to zero. They are not a subset of complementary precautions, as exclusive precautions offer the possibility of substitution between variables—they simply cannot be taken in conjunction. Mutual exclusions may present only for certain ranges or levels of individual precautions, or be contingent on exogenous conditions.

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<sup>264</sup> Mutually exclusive precautions sometimes present interesting challenges in determining causation, which are beyond the scope of this thesis. The normative complexities associated with them are reviewed within the context of overlapping precautions, explained hereinafter.

c. “NO PRECAUTION IS AN ISLAND”: INTERACTING PRECAUTIONS

Precautions interact. Their efficiency is nearly always correlated. This is an almost self-evident fact of life. Taking one precaution usually changes the marginal efficiency of another.<sup>265</sup> When interactions occur, two plus two will not necessarily equal four. It could equal three or five or even one.<sup>266</sup>

While our above discussion regarding the multidimensionality and predeterminacy assumptions tacitly assumed precautions are orthogonal and substitutable (in the simple sense that isoquant lines are downward-sloping), the discussion here relaxes that assumption in favor of a more realistic one. The following will review three basic categories of interactions between different precautions: negative synergies, overlaps and positive synergies. As we show, each category manifests with distinctive characteristics, explicated by differences in their impact on the overall shape of the production function, the shape of the isoquant lines, the marginal rate of technical substitution and the elasticity of substitution.

What is common to all interaction categories is this—applying the marginal approach is generally inadequate or of limited value. In the everyday scenario of interacting precautions, a marginal constrained analysis might lead to false positive and *vice versa*—finding no liability where one should exist, and finding liability where it should not be found.<sup>267</sup> Worse still, following the marginal approach might incentivize assorted inefficient or suboptimal behaviors

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<sup>265</sup> These interactions can affect the expected risk ( $P$ ), expected damage ( $L$ ) or both.

<sup>266</sup> To use our terminology, an outcome of three would reflect overlaps, an outcome of five would reflect positive synergies and an outcome of one would reflect negative synergies. When precautions are orthogonal, the outcome in this example would be four.

<sup>267</sup> The later cases, where the marginal approach will err in favor of the plaintiff, might result from temporal changes and interactions between different players in bilateral precaution settings, as discussed by Guttel, *The (Hidden) Risk of Opportunistic Precautions*, *supra* note 39. Guttel’s model only addresses strategic scenarios between two or more players, as opposed to interactions between precautions in unilateral settings.

by strategic players. In those cases, the golden standard of negligence fails on a fundamental level.

In a nutshell, when parties know at the *ex-ante* stage that they will only be subjected to a short-run review in the future, so that a future trier would likely consider their current actions constraints, their *ex-ante* incentives scheme changes dramatically. Specifically, prospective defendants might be tempted to make socially suboptimal or even inefficient choices, designed to best situate them to face a future marginal review. From a social policy perspective, this distorted incentive structure might be highly harmful. Repeatedly applying a short-run analysis, and making strategic choices designed to “outsmart” a constrained and myopic judicial review, is likely to increase long-run social costs. When tortfeasors repeatedly fail to make necessary long-run plans, and constantly attempt to maneuver their way into a more favorable *ex-post* position, society as a whole is likely to incur higher costs than if a more sensitive (and sensible) approach was applied by courts. Consider the following simple vignette:

A doctor deliberates between two tests for a patient, a CT and an MRI. Both tests are cost-efficient when taken alone, *i.e.* their costs are smaller than their respective expected benefits. However, sending the patient to both tests is inefficient, in the sense that the marginal benefit of a second test, be it CT or MRI, will not justify its cost.<sup>268</sup> Assume also that the CT test is cheaper, but an MRI test is more effective to that patient and will yield a higher social benefit.<sup>269</sup>

Under these circumstances, which test would the doctor choose?

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<sup>268</sup> In this example, the depreciation in the marginal benefit of the second test, CT or MRI, is a result of an overlap with the first test, as discussed hereinafter.

<sup>269</sup> So that the added benefit more than offsets the additional costs of the MRI test.

While the MRI is clearly the socially preferable choice, applying the marginal approach to this example is likely to incentivize the doctor to opt for the less desirable yet cheaper CT test. To see this, recall that the marginal approach does not review past taken actions anew, and considers them sunk costs. It only examines whether, under a preexisting state of constraints, the defendant could have taken a single additional cost-justified precaution. Knowing this, the doctor should realize that no liability would follow from choosing one test over the other, as long as one of the tests is eventually performed. Having been left with a *de-facto* choice between performing a CT or an MRI, a rational doctor should choose the least expensive test, in this case the socially suboptimal CT.<sup>270</sup>

If the doctor in this vignette was faced with an additional (third) course of action, for example an X-ray test, the number of possible alternative bundles of precautions would more than double, with each additional possible test exponentially increasing the number of possible permutations of tests.<sup>271</sup> As more and more possible combinations of tests are introduced, discovering the unconstrained *ex-ante* (or long-run) optimal solution will become progressively more difficult, and require more elaborate optimization methods. As Part VI will explain, such optimization methods inevitably necessitate multiple factors and degrees of freedom to be taken into account. For instance, they may require comparing various combinations of precautions the defendant could have taken and for sunk costs and omissions that occurred in the past to be contemplated or ignored. As this thesis claims, “perfect” optimization is

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<sup>270</sup> In reality, courts have found ways to impose liability in such cases, and in the above example might find the choice of a CT test over an MRI in breach of duty. However, such a ruling does not derive from a strict application of the marginal approach, and supports the claim that the marginal approach is unfit to optimize most real-life cases.

<sup>271</sup> When only two alternatives are possible, the possible courses of actions are: MRI, CT and MRI and CT. When an X-ray test is also available, the possible sets of alternatives are: MRI, CT, X-ray, MRI and CT, MRI and X-ray, CT and X-ray and CT, MRI and X-ray separately (assuming no test can be taken more than once and that the order of tests is inconsequential with respect to the resulting overall care). When the order of tests is significant, and tests can be taken more than once, the number of possibilities is unbounded.



practically impossible even under an everyday level of complexity, and will inevitably involve conflicting restraints between short-run and long-run incentives. The marginal approach, with its short-termed focus and limited review, will almost surely fall short of achieving efficient results in most scenarios. The following sections address why in more detail.

**i. NEGATIVE SYNERGIES**

**1) ECONOMIC FOUNDATIONS**

Negative synergies reduce the overall benefit derived from a specific set of precautions when compared to a subset of the same precautions. When they occur, taking certain precautions has a detrimental impact on the overall efficiency of care measures. Economically speaking, negative synergies denote a case where adding a particular precaution (or increasing its level) results in a negative marginal return, or diminishing total return.

Looking at a three-dimensional production space, negative synergies between precautions can manifest in inversions from upward-sloping to downward-sloping statures (or local “gorges” in a production “hill”), increases in the steepness of a downward-sloping segment of the production hill or a cross-section of it, and an increase in the distance between isoquant lines. The exact manner and boundaries of these presentations naturally depends on the terms and constraints of each production function.

When isoquants are drawn based on an overall production function, negative synergies can be indicated by upward-sloping and backward-bending isoquant lines. When isoquants lines are upward-sloping and backward-bending, an increase in the level of one precaution will decrease the overall level of safety, holding other variables constant. Conversely, decreasing the level of one precaution will increase the overall level of safety. Therefore, holding the level

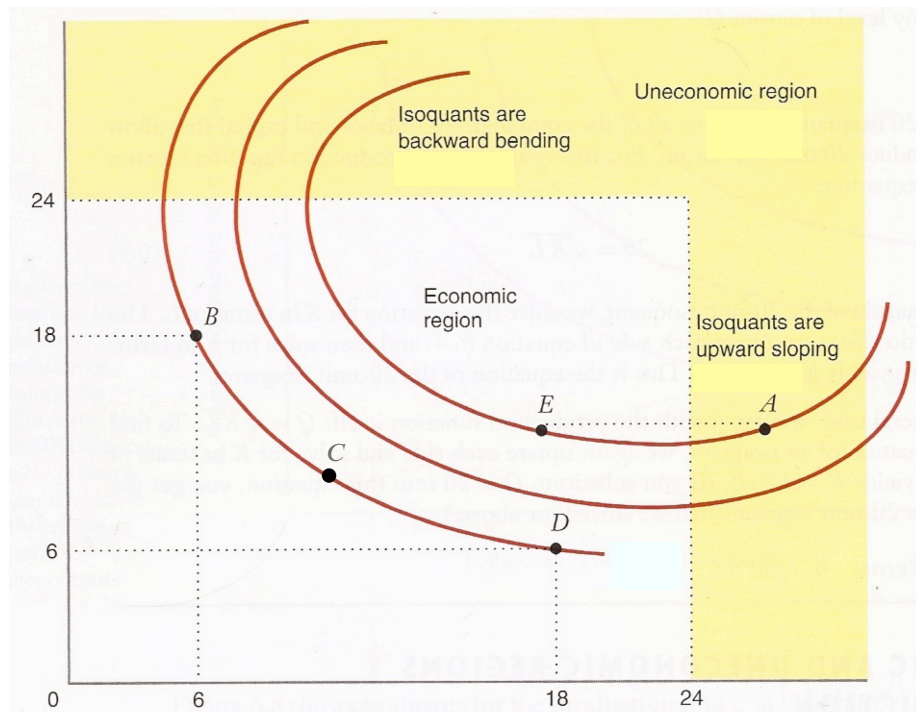
of safety production constant would require an increase of one or more variables in order to compensate for the diminishing total return resulting for the increase of the other variable. We can call this type of negative synergies “one directional,” as they allow for the detrimental effect of increasing one variable to be countered by an increase in other variables.

The regions on the total production function with upward-sloping and backward-bending isoquants can be defined as uneconomic regions of production. A tortfeasor operating in uneconomic regions of care production will always produce safety at a suboptimal cost, and as we shall soon demonstrate will be found in breach of duty by a marginal adjudication process, despite possibly overinvesting in precaution.<sup>272</sup> Figure IV.4 illustrates this case, marking uneconomic regions of safety in yellow.

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<sup>272</sup> Recall that substitutions between precautions often result in a decoupling between investment and precaution levels. Thus, a defendant might be found negligent despite overinvesting in precautions even when no negative synergies occur.

Figure IV.4: Uneconomic Regions along a Total Production of Safety Function<sup>273</sup>



The scenario illustrated in Figure IV.4 is common for precautions exhibiting monotonically diminishing marginal returns. As marginal returns diminish, their contribution to care might turn negative, and have a detrimental effect on overall safety. The upward-sloping or backward-bending section of the isoquant lines represent exactly that case, where an increase in the level of one variable past a particular point becomes harmful.

Alternatively, some negative synergies do not allow for any increase in the level of one variable to be countered by an incremental increase in the other, so that taking a certain precaution (or an increase in its level) would generally mark a diminution of the total output of care.<sup>274</sup> We can call this type of negative synergies “two directional,” as they do not allow for the detrimental effect of increasing one variable to be countered by an incremental change in

<sup>273</sup> Original chart taken from Besanko and Braeutigam, *Microeconomics*, *supra* note 211, at p. 198.

<sup>274</sup> Unless the negative synergy is limited to a specific segment or cross-section of the production function.

other variables. When such negative synergies occur, a particular level of care cannot be maintained as long as at least one of the precautions is not removed or decreased in level.<sup>275</sup> Such a presentation is usually unrelated to diminishing marginal returns, and derives from some adverse or conflicting interaction between two precautions.<sup>276</sup>

Regardless of the type of negative synergy, it is important to note that negative synergies can manifest anywhere along the production surface, not only on the extremities of the isoquant lines. Negatively synergies are often case-specific, and can be highly contingent on a particular alignment of variables. Precautions that result in diminishing total returns when taken in conjunction may not be inefficient when taken alone, together with other precautions, at other levels or under different external circumstances. It is perfectly possible—perhaps even common—for a precaution or set of precautions to be marginally efficient in one setting, yet harmful in another.

## 2) NORMATIVE REFLECTIONS

Negative synergies result in distinct normative challenges to negligence adjudication, and place considerable strain on the legal system's ability to craft efficient solutions in myriad settings. In the following, we address the normative implications of negative synergies in the negligence context. For clarity, our discussion will be divided between two perspectives: (i) Production of care in uneconomic regions; and (ii) distorted *ex-ante* incentives on the tortfeasor.

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<sup>275</sup> If the negative synergy is limited to a specific segment of cross sections, a non-incremental increase in the level of one precaution might increase the overall production of care, depending on the shape of the production function. For functions with more than two variables, this the result will obviously depend on all variables and their correlations.

<sup>276</sup> For instance, certain drugs can not only contradict each-others' positive effects, but also come together in a harmful manner. Such harmful effects can be limited to specific levels of each drug.

### Uneconomic Regions of Care Production

Producing care in uneconomic regions of production might entail disconcerting implications. Specifically, operating in these regions will necessarily result in the—by now familiar—normative tension between short-run and long-run optimization methods, and will always brand the defendant negligent from a marginal perspective. Consider the following example, based on Figure IV.4:

A defendant is operating at point *A*, which is on the uneconomic region of production of isoquant *EA*. The socially optimal combination of precautions is *B*, which is on the *BCD* isoquant. The level of care produced on isoquant *EA* is higher than the level of care produced on isoquant *BCD*. The marginal cost of all precautions is assumed to be positive and constant or strictly increasing.

How would the two basic approaches to negligence adjudication consider this case?

From a marginal *ex-post* perspective, the defendant operating at point *A* would be considered in breach of duty. To easily see why, notice that the defendant can efficiently reduce the level of precaution *x* from point *A* to at least the beginning of the uneconomic region of production (marked level 24). Since this change would have increased the overall level of care while decreasing its cost of precaution *x*, it would necessarily be marginally cost-justified. More generally, we can state, based on this example, that a defendant operating in uneconomic regions of production would always be found in breach of his duty of care if a marginal approach is applied, without need to specifically calculate the actual costs and benefits of all options.<sup>277</sup> The normative implications of this finding, however, might be highly problematic. For instance, in our example, the defendant will be found negligent even though he

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<sup>277</sup> Such a calculation might nonetheless be required in order to establish causation or damages.

overinvested in precaution and actually produced a higher level of overall safety than required by the exogenous duty of care (and more safety than produced by other defendants who would be found not negligent).

From an aggregated *ex-ante* perspective, a defendant operating at point *A* would not be found in breach of duty, as he exceeded the socially mandated level of care. To see this, notice that isoquant *EA* marks a higher level of care than the socially mandated minimum, marked by isoquant *BCD*. However, applying the aggregated approach to this case would produce inefficient short-run incentives on the defendant, and would not induce him to take marginally cost-justified precautions once the overall level of care exceeded the socially required minimum. While that should not be too alarming in uneconomic regions of production (where a reduction in the level of one precaution would be Pareto efficient and should already be in the defendant's interest),<sup>278</sup> recall that marginal *ex-post* improvements are often possible in economic regions of production, not only in non-economic ones, when suboptimal combinations of precautions are taken by the defendant. Therefore, a defendant operating in non-economic regions of production or taking suboptimal combinations of precautions might not make cost-efficient alterations as a result of the application of an aggregated negligence standard (as such alterations would require him to make *Kaldor-Hicks* efficient investments without internalizing their benefit).<sup>279</sup>

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<sup>278</sup> In the sense that they increase both the defendant's expected gain and social utility.

<sup>279</sup> Meaning that the social utility will increase, but the defendant would be worse off as a result of the change.

Distorted *ex-ante* Incentives on the Tortfeasor

Applying the marginal approach against the backdrop of negative synergies may also incentivize value destroying strategic behaviors, resulting from distorted *ex-ante* incentives on the defendant. When this occurs, suboptimal and inefficient long-run results are highly likely. To illustrate, consider Table 2, based on the *Hendricks* Case discussed in Part I:

Table 2: Negative Synergies and Distorted *ex-ante* Incentives on the Tortfeasor

<b>Precaution Level</b>	<b>Cost</b>	<b>Risk (PL)</b>	<b>Risk Decrease</b>	<b>Social Cost</b>
<b>Actual</b>	10,000	50,000	--	60,000
<b>Lifeguards</b>	45,000	10,000	40,000	65,000
<b>Fence</b>	14,000	20,000	30,000	44,000
<b>Barricades</b>	10,000	30,000	20,000	50,000
<b>Fences + Barricades</b>	24,000	22,000	28,000	56,000

In this example, the table values remain exactly as they were in Grady’s original argument. We assume, however, that placing signs is no longer possible, and that there is a negative synergy between the fence and the barricades. To make this scenario more realistic, imagine—based on the *Hendricks* storyline—that teenagers wishing to enter the flooded mine move the barricades and use them to climb over the fence. Placing barricades would therefore diminish the efficiency of the fence: while the fence alone reduces the risk by \$30,000, adding barricades to it results in an overall risk reduction of only \$28,000. Although both the fence and barricades are individually and conjunctively cost-efficient, only building a fence is

optimal, as it reduces the social cost to a minimum (\$44,000). Applying both precautions is not optimal.

Under these conditions, once barricades have been set up, adding a fence to it is no longer cost-justified, as it will reduce the risk by \$8,000 (\$28,000-\$20,000) at a cost of \$14,000. Conversely, once a fence is built, adding barricades will not be cost-justified, and in fact will increase the risk by \$2,000 (\$30,000-\$28,000) at a social cost of \$10,000. As a result, if a marginal constrained analysis is employed, after barricades are in place a defendant will not be considered negligent for not adding a fence, and after a fence is built a defendant will not be considered negligent for not adding barricades. Knowing this in the *ex-ante* stage, a prospective defendant would be left with a *de-facto* choice between building a fence or setting up barricades. A strategically minded defendant is therefore likely to pick the least expensive precaution, and in this example set up barricades rather than building the socially optimal fence.

Perhaps it would be helpful to further illustrate the tortfeasor's options and incentive scheme using an extensive-form decision tree. This decision tree shows all possible moves and choices a tortfeasor faces at each decision point. The number of leaf-nodes represent the number of outcomes in which the game can end. As we assume a complete and deterministic model, it is possible to "solve" the game using simple backward induction, or retrograde analysis. Our implied contention here is that negligence models ought to regularly use extensive-form decision trees to describe and solve unilateral precaution puzzles, let alone bilateral precaution puzzles, and that not doing so reflects the conventional model's misguided disregard of interacting precautions and path dependencies in sequential settings.<sup>280</sup>

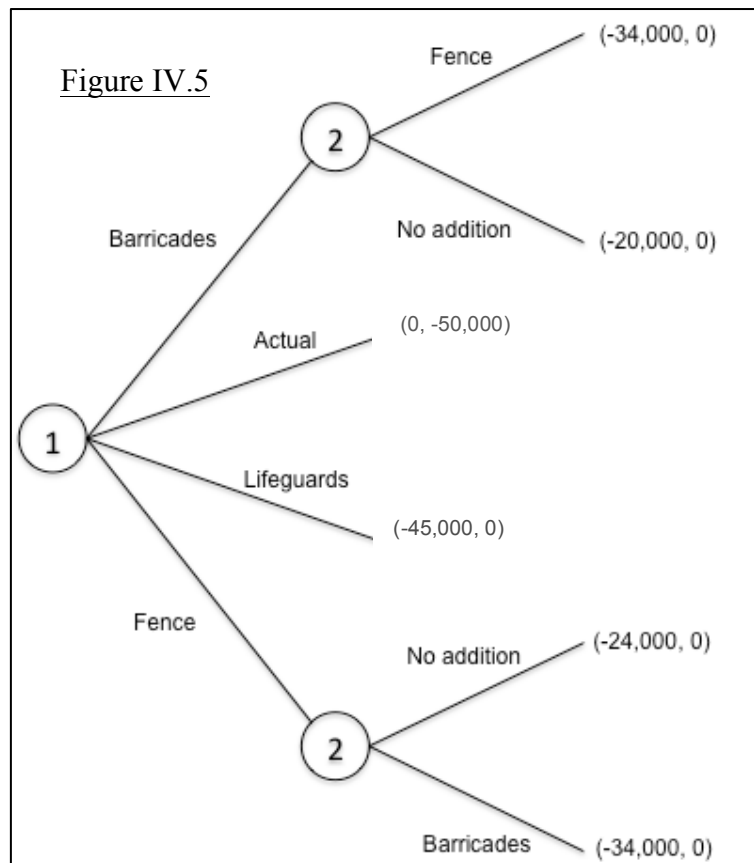
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<sup>280</sup> Indeed, I have found no use of 'extensive-form' decision trees in tort literature with regards to unilateral



Figure IV.5 illustrates the basic *ex-ante* decision tree facing the defendant in this example. The numbers on non-leaf nodes represent the move number the defendant takes. The first number in parentheses on leaf nodes represents the overall cost of precautions, and the second number in parenthesis represents the liability the defendant expects when taking the preceding tree-branch. For simplicity, we assume that lifeguards are mutually exclusive, and cannot be taken in conjunction with other precautions.<sup>281</sup>

Reflect first on the features of this puzzle. Clearly, if a marginal approach is applied, the defendant in this example would not anticipate being found in breach of duty for taking any of the three possible precaution-branches. The only leaf node where the defendant anticipates liability under a marginal analysis is “Actual,” which in fact represents not taking any



additional precaution beyond the base level (and therefore does not require any additional expenditure by the defendant beyond already-taken sunk costs).<sup>282</sup>

precautions.

<sup>281</sup> For instance, assume that barricades and fences make it so hard for lifeguards for enter the premise that they refuse to work as long as they are constructed.

<sup>282</sup> We assume, in this tree chart and the following, that the original investment in care (or “Actual” level of care per Grady) is sunk, and exogenous to the model.

Figures IV.6 and IV.7: Negative Synergies and Distorted *ex-ante* Incentives on the Tortfeasor, demonstrate a retrograde analysis of this setting:

In Figure IV.6, we begin by folding the second level or tier of the tree. As was our conclusion before, doing so illustrates that the defendant would prefer not to add a fence to already-constructed barricades (as  $-20,000 > -34,000$ ) and not to add barricades to an already-built fence (as  $-24,000 > -34,000$ ). The paths of the dominant strategies at the second tier are marked in red.

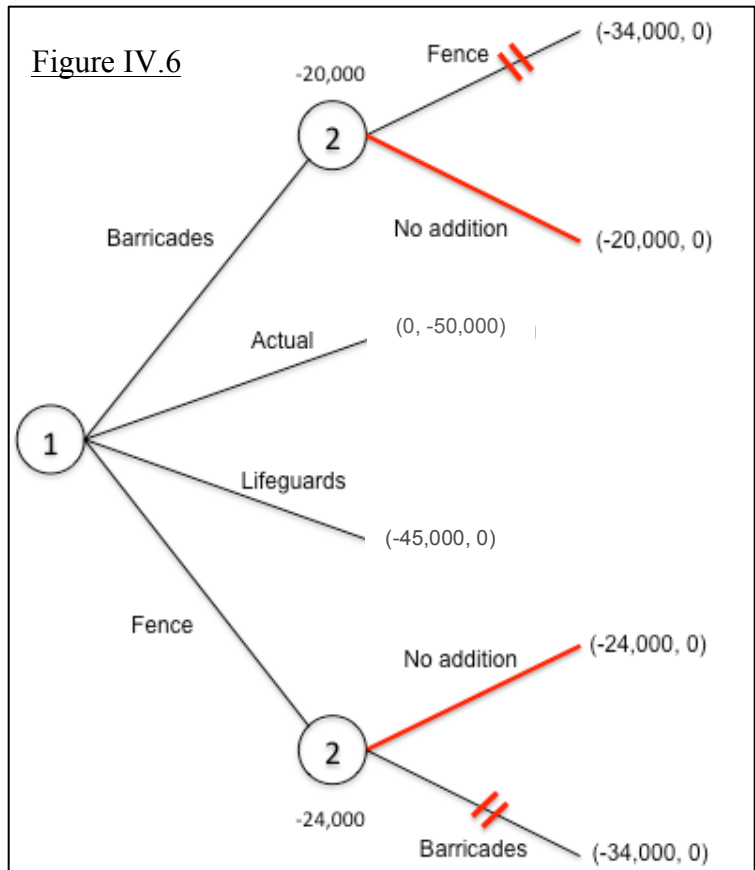
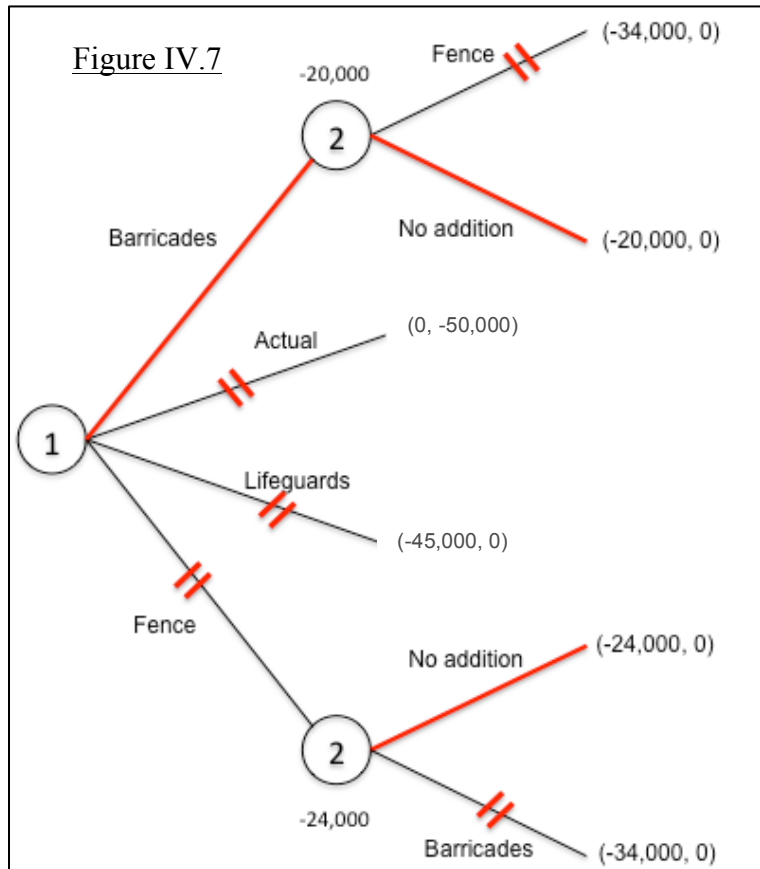


Figure IV.7 completes the folding of the decision tree, and demonstrates that at the first decision point, the defendant would prefer to place barricades to building a fence (as,  $-20,000 > -24,000$ ), hiring lifeguard (as  $-20,000 > -45,000$ ) or maintaining his original level of care (as,  $-20,000 > -50,000$ ). The paths of the dominant strategies are again marked in red. Thus, we can conclude, based on this example, that applying a marginal constrained approach against the background of negative synergies might induce a defendant to take socially suboptimal choices, exploiting the purely short-run perspective it employs.



## ii. OVERLAPS

### 1) ECONOMIC FOUNDATIONS

Precautions can also overlap. Overlaps and negative synergies share many similarities between them, and in some contexts can be thought of as particular cases of one another. Negative synergies, as we have seen, occur when the overall benefit derived from a set of precautions is lower than any subset of the same precautions. Overlaps, on the other hand,

occur when the efficiency of a combination of precautions is simply lower than the sum of the same precautions' individual benefits. In reality, overlaps are extremely prevalent, and common to most real-world situations.<sup>283</sup> Given their prevalence and importance, our discussion in this subsection will take a more expansive form.

Overlaps may be viewed as a type of interaction, where taking one precaution actually changes the function of another, and diminishes its marginal efficiency without rendering it negative.<sup>284</sup> Alternatively, some overlaps simply result from an exogenous quality of increasingly harder-to-prevent marginal risks, or "survival of the fittest risks". In most negligence cases, some risks are easier (or cheaper) to prevent than others, and the overall risk becomes harder and harder to eliminate with each additional precaution taken. As a result, the marginal benefit of expenditure in precautions generally diminishes. When that is the case, and it usually is, the order at which precautions are taken affects each precaution's marginal efficiency, as more resistant risks are left standing for every additional precaution. In other words, as precautions are taken at increasingly higher levels, the marginal efficiency of any additional precaution, or any increase in its level, would be lower than it would have been if previous precautions were not taken.

To illustrate the reality of harder-to-prevent marginal risks, consider Gladwell's description of a study for the treatment of heavy smoking, which compared the effect of

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<sup>283</sup> It is worth noting that overlaps are even implicit in Grady's own example. To see this, notice that in Table 1, signs, lifeguards and the fence must at least overlap (or be mutually exclusive), as each precaution cannot maintain the same marginal efficiency once another precaution has been taken. For instance, once lifeguard are employed and reduce the expected risk by \$40,000, the marginal efficiency of signs, barricades and the fence would diminish from \$20,000-\$30,000 to no more than \$10,000, the remaining overall risk. See *supra* note 256; and *Grady, supra* note 1.

<sup>284</sup> At which case it would have been considered a negative synergy.

combining smoking counseling with (i) a placebo drug; (ii) nicotine patches; and (iii) Zyban, an antidepressant affecting the release of certain brain neurotransmitters:

“[...] 23 percent of smokers given a course of anti-smoking counseling and a placebo quite after four weeks. Of those given counseling and the nicotine patch, 36 percent had quite after four weeks. The same figure for Zyban, though, was 49 percent, and of those heavily addicted smokers given both Zyban and the patch, 58 percent had quite after a month.”<sup>285</sup>

If we consider counseling a background constraint, the study shows that nicotine patches reduced smoking by 13 percent (36%-23%), Zyban by 26 percent (49%-23%) and the combination of nicotine patches and Zyban by 35 percent (58%-23%). Thus, not surprisingly, nicotine patches and Zyban display with overlaps: When Zyban is administered as a sole treatment, its marginal efficiency is 26 percent. When it is administered as a second treatment to nicotine patches, its marginal benefit is only 22 percent (58%-36%). Similarly, when nicotine patches are administered as a sole treatment, their marginal efficiency is 13 percent, while as a second line of care they only yield a 9 percent marginal improvement (58%-49%). Comparable results are typical to most forms of therapeutically treatments, and more generally to most precautionary measures and negligence settings.

It is not hard to think of overlaps in the caselaw context, where they exert unique normative difficulties. For instant, reflect on two of the possible precautions listed in the *Mimoni* Case: posting warning signs and providing instructions. We can assume that both precautions have diminishing marginal returns when taken alone. Additionally, they very likely overlap, in the sense that once one unit of signs is posts, the marginal efficiency of the first quantity of instructions would be lower than if signs were not previously posted.

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<sup>285</sup> Gladwell, *The Tipping Point*, *supra* note 143, at p. 247.

Alternatively, the first unit of signs would not be as (marginally) efficient if instructions were already provided to the riders than if they were not. Both cases reflect a simple truth—precautions usually overlap, and marginal risks are typically harder to eliminate.

To an extent, recognizing overlaps between some precautions can explicate the *Mimoni* court’s hesitation to set an *a priori* level of care for each precaution separately, while holding that helmets must be issued under all circumstances. When the marginal efficiency of each precaution is contingent on another, attempting to optimize each type of precaution separately would be of little value.<sup>286</sup> Therefore, if we assume that posting signs and providing instructions overlap, prescribing a separate duty of care to each of them might result in problematic outcomes. When, on the other hand, precautions do not overlap, it might be easier to prescribe rules of thumb and more specific duties pertaining to their use, irrespective of other variables.<sup>287</sup> Thus, if we assume that the marginal efficiency of helmets does not overlap with other precautions (for instance, because helmets reduce the risk of head injury, which no other precaution helps limit), or at least that they always yield a higher benefit than their cost irrespective of other variables and constraints, the holding of the *Mimoni* court would seem consistent with efficiency considerations. Similarly, the binding of different precautions into three categories or groups might reflect the *Mimoni* court’s intuition that the precautions in each category overlap amongst themselves, but not with precautions on other groups.<sup>288</sup>

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<sup>286</sup> As we already discussed, it might sometimes be efficient for courts to regulate behavior by prescribing specific levels of particular precautions, when a specific combination or precautions is the social optimum from a cost-benefit analysis perspective. However, recall that it is possible for suboptimal combinations of precautions to be on the same isoquant, or even a higher isoquant, than the social optimum. The normative tension arising from these issues are discussed throughout this thesis.

<sup>287</sup> Doing so would also depend on the type and distribution of possible risks, which is outside the scope of this thesis. In a nutshell, the “*PL*-side” of the Hand Formula requires, much like the precaution side of the Formula, an aggregation of materialized and non-materialized risks. Some types of precautions can overlap with regards to preventing certain risks, while others will not.

<sup>288</sup> Or at least that taking at least one precaution of each group would always be marginally cost-justified.

**2) NORMATIVE REFLECTIONS: DISTORTED EX-ANTE INCENTIVES ON THE TORTFEASOR**

As in the case of negative synergies, the prospect of overlaps between precautions also entails opportunities for strategic behaviors and suboptimal results, which have generally eluded legal scholarship. Consider the following:<sup>289</sup>

Table 3: Overlapping Precautions and Distorted *ex-ante* Incentives on the Tortfeasor, a Constrained Analysis

<b>Precaution Level</b>	<b>Cost</b>	<b>Risk (PL)</b>	<b>Risk Decrease</b>	<b>Social Cost</b>
<b>Actual</b>	10,000	50,000	--	60,000
<b>Lifeguards</b>	45,000	10,000	40,000	65,000
<b>Fence</b>	14,000	20,000	30,000	44,000
<b>Barricades</b>	10,000	30,000	20,000	50,000
<b>Fences + Barricades</b>	24,000	18,000	32,000	52,000

In this simple example, employing both a fence and barricades is cost-efficient, as is taking each of them separately.<sup>290</sup> Unlike the case of negative synergies, the overall benefit derived from taking both precautions is higher than taking each of them individually. However, much like the case of negative synergies just discussed, adding a second precaution, be it a fence or barricades, is inefficient. Once a fence is built, it is not longer cost-justified to

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<sup>289</sup> Throughout the following examples, we assume that the specific order precautions are taken is immaterial, in the sense that the social cost of, for instance, erecting barricades and then building a fence is equal to building a fence and then erecting barricades.

<sup>290</sup> This example is very similar, in its fundamental characteristic, to the smoking prevention study, discussed above.

erect barricades, and *vice versa*. As before, in these settings a prospective defendant will face a *de-facto* choice between precautions. Knowing that no liability will follow from choosing one precaution over another, a rational defendant should take the cheapest precaution, and in this case erect barricades rather than building the socially optimal fence.

As before, we can illustrate the tortfeasor's available options and possible sequential strategies using an extensive-form decision tree. There is no need to do so here, as Figures IV.5-IV.7 (based on the data pattern in Table 2) actually present an identical pattern to the decision tree facing the tortfeasor faced with on the data in Table 3. Indeed, the only difference between the two tables lies in the overall social cost and risk decrease rubrics derived from building a fence and erecting barricades in conjunction. As this difference does not alter the defendant's expected liability or expenditure, his incentive scheme would not change in this case. We can therefore rely on our analysis of Figures IV.5-IV.6 and conclude that applying a marginal constrained approach against the background of overlaps might induce a defendant to take socially suboptimal choices, exploiting the purely short-run perspective of the marginal approach.

### **3) NORMATIVE REFLECTIONS: SEMI-CONSTRAINED ANALYSIS**

From this point, it is not difficult to conceive of increasingly complicated examples that, though far from amounting to real-life complexity, would baffle even more elaborate and expansive standards of review, that apply fewer and fewer constraints. One example is a hypothetical "alternative precaution not-taken" standard. This standard allows a court to look "one step" back into actions taken by the defendant in the past, and inquire whether he could have taken a superior and cost-justified *alternative* precaution, instead of a precaution that was



actually taken. In that, this hypothetical standard applies a broader review of past behaviors than prescribed by the marginal approach, and allows for a qualified evaluation of sunk costs. More technically, it allows for one degree of freedom to be added to an otherwise constrained short-run review. We can therefore refer to this standard as semi-constrained. Naturally, the number of constraints applied in negligence cost-benefit analysis can vary, and the alternative precaution not-taken represents one out of a vast range of possible semi-constrained methods.

As Table 4 demonstrates, social inefficiencies and *ex-ante* strategic behavior might persist even if a court applies this hypothetical alternative precaution not-taken standard. In fact, as we examine more and more complex scenarios, it becomes obvious that no single cost-benefit analysis scheme can guarantee optimal results for every setting.<sup>291</sup> Consider the following:

Table 4: Overlapping Precautions and Distorted *ex-ante* Incentives on the Tortfeasor, a

Semi-Constrained Analysis

<b>Precaution Level</b>	<b>Cost</b>	<b>Risk (PL)</b>	<b>Risk Decrease</b>	<b>Social Cost</b>
<b>Actual</b>	10,000	50,000	--	60,000
<b>Lifeguards</b>	45,000	10,000	40,000	65,000
<b>Fence</b>	10,000	28,000	22,000	48,000
<b>Barricades</b>	12,000	30,000	20,000	52,000
<b>Signs</b>	8,000	26,000	24,000	44,000
<b>Signs + Fence</b>	18,000	18,000	32,000	46,000

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<sup>291</sup> There is, however, a relationship between a scenario's complexity and the maximum number of degrees of freedom that can be applied to it. The reason why no single method would always induce optimal results to all settings goes back to the basic tension and conflicting incentive schemes between long-run and short-run optimization, discussed throughout this thesis.

<b>Signs + Barricades</b>	20,000	15,000	35,000	45,000
<b>Fence + Barricades</b>	22,000	10,000	40,000	42,000

In this example, the socially optimal course of action is a combination of a fence and barricades, which would minimize the social cost to \$42,000. Under a marginal review, neither the barricades nor the fence may be taken alone, as other precautions can be cost-justifiably added to both of them. However, if signs are placed first, a defendant will not be considered negligent under a marginal analysis for not adding barricades or a fence, as adding the fence or barricades to signs is not cost-justified.

Under the alternative precaution not-taken standard, the defendant will also not be considered negligent for only placing signs, as signs are marginally superior to both the fence and barricades (taken separately)<sup>292</sup> and reduce the risk to the defendant at a higher rate.<sup>293</sup> Only the combination of barricades and the fence together is socially superior to placing signs in this case. Thus, Table 4 predicts that a rational defendant would strategically choose the socially suboptimal yet cheaper option of placing signs to the optimal combination of building a fence and setting up barricades. This inefficient incentive would not be negated even if the court applies the semi-constrained alternative precaution not-taken standard.

Analyzing the defendant's possible strategies using an extensive-form decision tree offers more insights into this example, and compliments our discussion throughout Part IV.

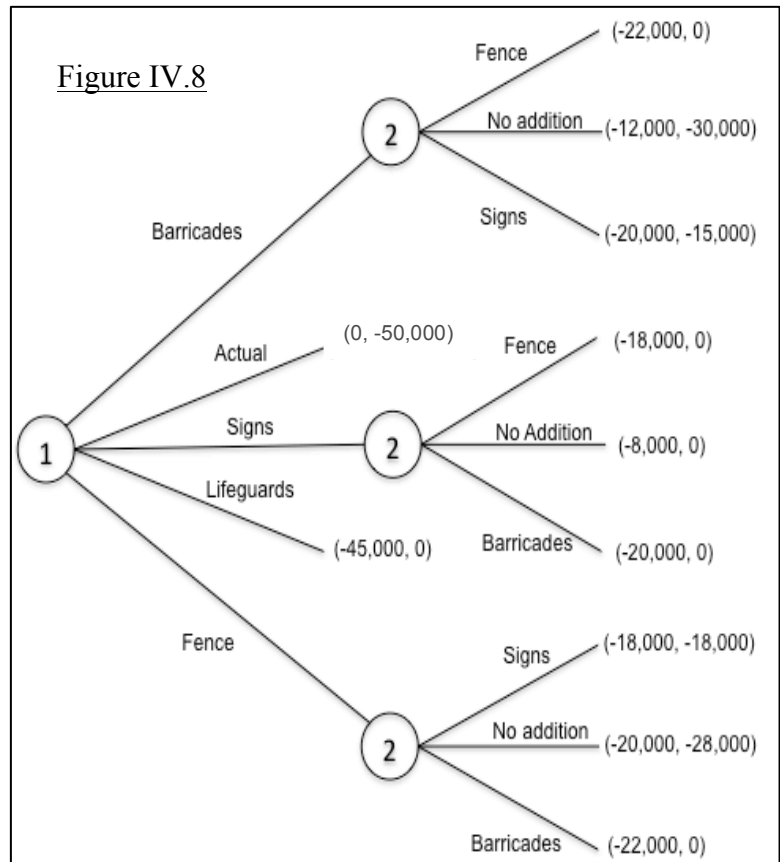
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<sup>292</sup> As \$44,000 (social cost of setting up signs) < \$48,000 (social cost of building a fence) < \$52,000 (social cost of erecting barricades).

<sup>293</sup> As \$24,000 (risk reduction of setting up signs) > \$22,000 (risk reduction of building a fence) > \$20,000 (risk reduction of placing barricades).

We begin this discussion with Figure IV.8: Overlapping Precautions and Distorted *ex-ante* Incentives on the Tortfeasor, a Semi-Constrained Analysis, which is based on the data in Table 3.

As before, the left number in parenthesis will denote the overall cost of precautions at the pertinent leaf node, and the right number indicates the expected liability foreseen by the tortfeasor, this time



under an alternative precaution not-taken standard. We assume that lifeguards are mutually exclusive, and cannot be taken in conjunction with other precautions.

Before drawing overall conclusions from this example and revisiting our above solution, it would be useful to point to the key feature arising from Figure IV.8 with regards to the defendant's liability and incentive scheme:

*First*, unlike our previous example, notice that about half of the terminal nodes in Figure IV.8 result in the defendant being found liable. This change is mostly a result of the heightened scrutiny brought by the alternative precaution not-taken standard.<sup>294</sup> As the negligence standard becomes more expansive and elaborate, and allows for more degrees of

<sup>294</sup> In calculating the expected harm, we assumed that court do not offset risks. On that, see Ariel Porat, *Offsetting Risks*, 106 MIC. L. REV. 243 (2007).

freedom and long-run consideration to be taken into account by adjudicators, the scope of possible liability would generally rise. Distinctly, acts and omissions that would not be considered a breach of duty under a sternly constrained analysis might be viewed as a breach of duty once some constraints are removed.<sup>295</sup>

*Second*, taking the combination of barricades and the fence will never be considered a negligent choice, as it reduces the overall risk of accidents to a minimum (and is socially optimal). Hiring lifeguards, however inefficient, will also not be considered negligent for the same reason—it reduces the overall risk to the same minimum (\$40,000), though at a higher cost. Importantly, when signs are placed first, the defendant will not be found in breach of duty if not additional precautions is added to them in the second node. As adding either the fence or barricades to already-placed signs is not cost-justified, the defendant will not be considered negligent for not adding either of them (and if one of them is added in the second node, the defendant would not be considered negligent for not choosing the other under the alternative precaution not-taken standard, as both options are not cost-justified at that node to begin with).<sup>296</sup>

*Third*, placing only barricades or only the fence, without adding the other soon after, would result in finding the defendant negligent. After barricades are erected, adding a fence to them would be cost-efficient and therefore mandated. Adding signs to barricades would also be cost-efficient, but would not exempt the defendant from liability, as that addition would be

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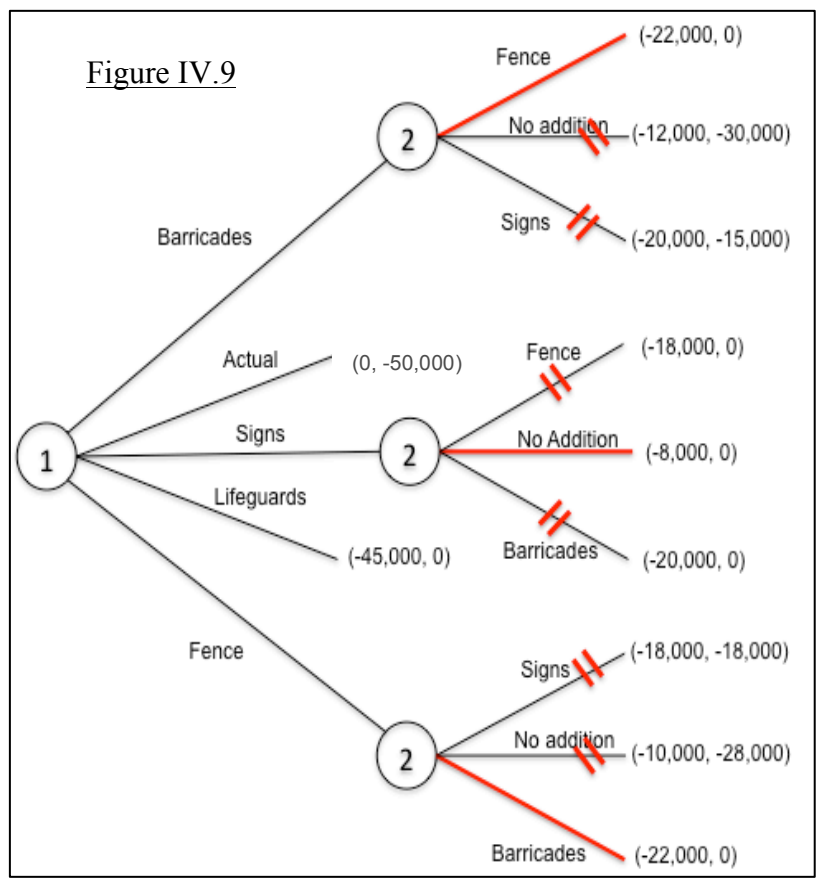
<sup>295</sup> Alternatively, however, as we already noted and will further explore in Part V, certain combinations of precautions might be considered negligent under a constrained analysis, but not when an *ex-ante* unconstrained approach is applied.

<sup>296</sup> For simplicity, we assume in this example that all three precautions—signs, barricades and the fence—cannot be taken together.

inferior when compared to adding a fence.<sup>297</sup> The paths of raising barricades and then placing signs or doing nothing would therefore be considered negligent under the alternative precaution not-taken standard. On the opposing limb, after a fence is built, adding barricades to it would be cost-justified and therefore mandated under the prevailing standard. Adding signs to an already-built fence would be cost-justified but suboptimal when compared to adding barricades, and would therefore result in placing liability on the defendant under the alternative precaution not taken standard.<sup>298</sup> The paths of building a fence and then placing signs or doing nothing would therefore be considered negligent under the alternative precaution not-taken standard.

Figures IV.9 and IV.10: Overlapping Precautions and Distorted *ex-ante* Incentives on the Tortfeasor, a Semi-Constrained Analysis, demonstrate the solution to this example using retrograde analysis technique:

In Figure IV.9, we begin by folding the second level or tier of the tree. On the top arm of the tree, as already described, the defendant would prefer to add a fence to

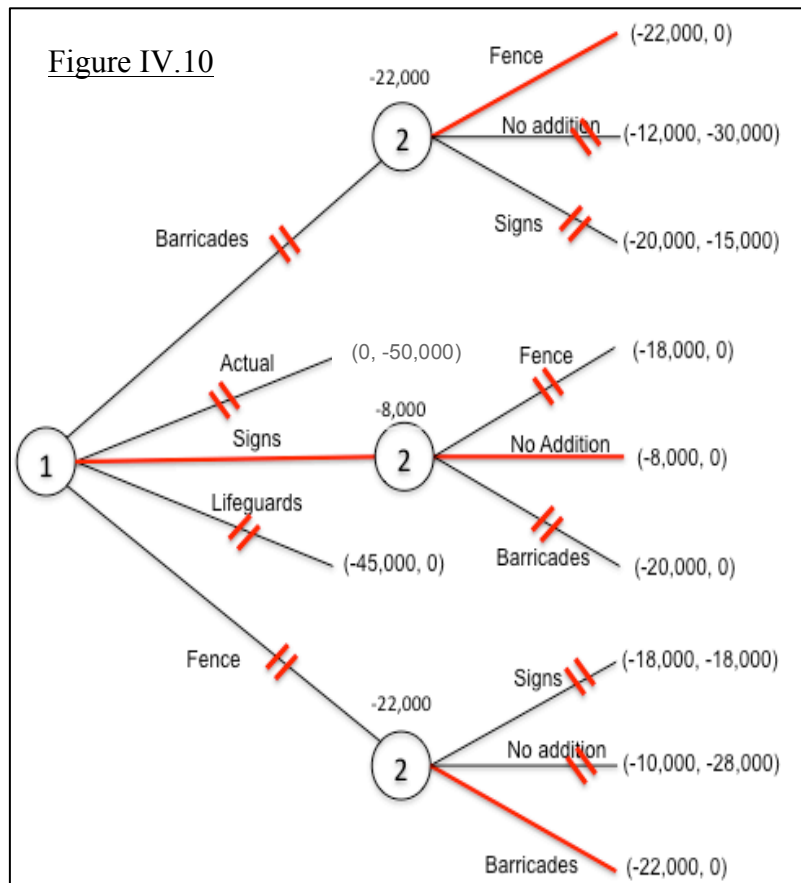


<sup>297</sup> Adding the fence would increase the social benefit by a higher margin than signs (\$10,000 > \$7,000) and the combination of barricades and fence is superior in terms of risk reduction (\$40,000 > \$35,000).

<sup>298</sup> Adding barricades to an already-built fence would result in a higher social gain than adding signs (\$6,000 > \$2,000) and the combination of barricades and the fence is superior in terms of harm reduction (\$40,000 > \$32,000).

already-raised barricades over doing nothing or adding signs, as that would minimize his expected costs in that arm (as,  $-22,000 > -35,000 > -42,000$ ). On the bottom arm, the defendant would prefer adding barricades to an already-built fence to doing nothing or adding signs (as,  $-22,000 > -36,000 > -38,000$ ). On the middle arm, the defendant would prefer not to add any precaution to already-placed signs (as,  $-8,000 > -18,000 > -20,000$ ). The paths of the dominant strategies are marked in red.

Figure IV.10 completes the folding of the decision tree. It demonstrates that the defendant would prefer to post signs to any other option on the first decision node, as posing signs would be preferable to building a fence and barricades or barricades and fence, hiring lifeguards or maintaining the original level of care (as,  $-8,000 > -22,000 > -45,000 > -50,000$ ). The paths



of the dominant strategies are again marked in red. We can therefore conclude, based on this example, that the alternative precaution not-taken might also induce the defendant to take *ex-ante* suboptimal or inefficient strategic choices, when such choices would enable him to manipulate a semi-constrained analysis employed by courts.

More disturbingly, notice that for both negative synergies and overlaps, it can sometimes be in the prospective defendant's interest to employ not only suboptimal precautions, but also inefficient ones, so long as the inefficient precautions are cheap and no additional cost-justified precaution can efficiently be added to them. In this extreme scenario, a rational defendant will take inferior or inefficient actions in order avoid liability for not taking certain efficient (yet expensive) actions.

#### **4) NORMATIVE REFLECTIONS: THE PREDETERMINACY ASSUMPTION AND PRODUCTION THEORY REVISITED**

A closer examination of Table 4 and Figures IV.8-IV.10 allows us to draw additional insights, and reinforce some of our previous conclusions with regards to the predeterminacy assumption and production theory:

From the perspective of predeterminacy assumption, our analysis illustrates that the outcome derived from applying a constrained or semi-constrained negligence review is highly path-dependent. Interactions between precautions render the short-run optimal result at each stage, and the judicial outcome derived for the method employed, extremely contingent on past-taken actions and future available options. The impact of posting signs in our previous example is a good example of that. If signs are placed as a first precaution, not only are they on the defendant's preferred path, but also no other precautions are required in addition to them for the defendant to avoid liability. If, on the other hand, signs are posted as a second precaution, after barricades or the fence are built, not only are they no longer on the defendant's preferred path, but also they result in placing liability on the defendant. Thus, in this example, a defendant who would only post signs would be found not liable under a constrained or semi-

constrained analysis, while a defendant who would build a fence or barricades and then post signs would be found liable. The normative difficulties of this result are clear: while the first defendant would reduce the overall harm by \$24,000 and be found not liable, the second would reduce the overall harm by \$32,000-\$35,000 and be found liable. It would therefore be accurate to say that path dependencies further exacerbate the innate divide between constrained and unconstrained forms of optimization, and render any form of constrained analysis susceptible to assorted inefficiencies. Against the backdrop of interactions, the conventional predeterminacy assumption—is simply wrong.

From a production theory perspective, the data shows little to no correlation between the overall production of care, the overall cost of taking precaution, the expected detriment to the plaintiff and social efficiency. To facilitate a review of this discrepancy, Table 5 compares the ranking of the different precautionary bundles, assuming an alternative precaution not-taken standard is in effect, using the following columns-rankings: (i) social cost and desirability; (ii) defendant's preference; (iii) plaintiff's preference; and (iv) overall level of care, or isoquants of risk reduction:



Table 5: Social Cost, Defendant's Preference, Plaintiff Preference and Over Level of

Care Compared

Precaution Bundle	# Social Cost	# Defendant Preference	# Plaintiff Preference	# Isoquant
<b>Fence + Barricades</b>	1 (42,000)	4 (22,000)	2 (10,000)	1 (40,000)
<b>Barricades + Fence</b>	1 (42,000)	4 (22,000)	2 (10,000)	1 (40,000)
<b>Signs</b>	2 (44,000)	1 (8,000)	5 (26,000)	4 (24,000)
<b>Signs + Barricades</b>	3 (45,000)	3 (20,000)	3 (15,000)	2 (35,000)
<b>Barricades + Signs</b>	3 (45,000)	5 (35,000)	1 (0) <sup>299</sup>	2 (35,000)
<b>Signs + Fence</b>	4 (46,000)	2 (18,000)	4 (18,000)	3 (32,000)
<b>Fence + Signs</b>	4 (46,000)	6 (36,000)	1 (0)	3 (32,000)
<b>Fence</b>	5 (48,000)	7 (38,000)	1 (0)	5 (22,000)
<b>Barricades</b>	6 (52,000)	8 (42,000)	1 (0)	6 (20,000)
<b>Actual</b>	7 (60,000)	10 (50,000)	1 (0)	7 (--)
<b>Lifeguards</b>	8 (65,000)	9 (45,000)	2 (10,000)	1 (40,000)

Compare the first-best social outcome, indicated in the first two rows (fence and barricades and barricades and fence) with the worse possible social outcome, indicated in the last row (lifeguards). Both lifeguards and the combination of fence and barricades are equally effective,<sup>300</sup> even though lifeguards require more than double the budget required to build the combination of the fence and barricades. While lifeguards and the bundle of barricades and

<sup>299</sup> The plaintiff's top preference is full compensation. We assume the plaintiff is indifferent between monetary compensation and not being harmed.

<sup>300</sup> As they reduce the overall harm by \$40,000 to a total of \$10,000.

fence are both on the top isoquant in terms of harm prevention (40,000), the combination of barricades and fence is the optimal combination of precautions in that isoquant, and is actually the overall socially optimal solution, while lifeguards are not even cost-efficient,<sup>301</sup> and would result in the worse possible social outcome. Another way to look at this divide is this—while a plaintiff would be indifferent between the defendant hiring lifeguards or taking a combination of fence and barricades,<sup>302</sup> there are no less than nine precautionary options the defendant would prefer to hiring lifeguards, and only one (doing nothing) that would offer the defendant a lower return under an alternative precaution not-taken standard.<sup>303</sup> Table 5 therefore illustrates our basic contention that there is no necessary correlation between social costs, overall costs of precautions and the elevation of the isoquant lines.

It is also useful to compare the first two rows (barricades and the fence and the fence and barricades) to the third (signs). While the combination of fence and barricades is socially optimal, there are no less than three combinations of precautions (all starting with posting signs) the defendant would choose over it. In other words, the misalignment between the social optimum and the incentive scheme facing the defendant runs deep, and would induce the defendant to take a number of strategic suboptimal choices rather than taking the socially desired one. Furthermore, notice that the defendant's likely choice of placing only signs is not

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<sup>301</sup> As they reduce the overall harm by \$40,000 at a cost of \$45,000. Lifeguards are the only precaution (or bundles of precautions) that is not cost-justified. We assume no ex-ante bargaining is possible between prospective defendant and plaintiff.

<sup>302</sup> As the plaintiff's expected harm under both options is identical (\$40,000) and he would not receive damages whether the defendant hires lifeguards or builds a fence and barricades.

<sup>303</sup> The fact that the defendant would prefer to hire lifeguards to doing nothing is problematic in and of itself, as hiring lifeguards is socially inefficient.

The combinations the defendant would prefer to hiring lifeguards are: posting signs (at an overall cost of 8,000 to the defendant); signs and fence (18,000); signs and barricades (20,000); barricades and fence (22,000); fence and barricades (22,000); barricades and signs (35,000); fence and signs (36,000); a fence (38,000) and erecting barricades (42,000). The only course of action inferior to hiring lifeguards, from the defendant's perspective, is doing nothing and maintaining the actual level of care (50,000).

only socially suboptimal and placed on the fourth-ranked (out of seven) isoquants of harm prevention, but would also place the plaintiff in the worst possible state when compared to all other courses of action (as he will incur an expected harm of 26,000 without compensation). If a purely marginal approach is applied, the divide between the preferences of both parties, the isoquants of harm reduction and the social ranking of precautionary bundles would naturally change, but the basic misalignment between them, and the inefficient incentives they bring, would persist.

### **iii. POSITIVE SYNERGIES**

#### **1) ECONOMIC FOUNDATIONS**

Positive synergies increase the overall return of a set of precautions when compared to the aggregated efficiency of its components. When only positive synergies occur, taking certain precautions has a beneficial impact on the marginal efficiency of others, so that the overall level of care produced is higher than the aggregated benefits of the individual subparts. As with negative synergies and overlaps, positive synergies can be highly case-specific, and limit themselves to designated precautions, precaution levels or exogenous circumstances. A precaution might generate a positive synergy when the stars are aligned one way, but spawn other outcomes when the stars are aligned differently.

Looking at a three-dimensional production hill, positive synergies between precautions can manifest in various ways. For instance, they may transpire in inflections between concave and convex upward-sloping elevations, an increase in the steepness of the production hill (or a cross-section of it), and a decrease in the distance between isoquant lines. The exact manner

and boundaries of these presentations will obviously depend on the terms and constraints of each production function.

When precautions come together to create a positive synergy, applying the marginal approach might lead to suboptimal judgments. More disturbingly, in some cases, where taking certain precautions individually is not cost-effective but taking them in conjunction is cost-justified, a marginal analysis is likely to lead to a finding of no liability where one should exist, and encourage strategic behaviors by potential tortfeasors. Finally, the workings of positive synergies serve to exacerbate the innate tension between short-run and long-run optimization, and shed new light on this insoluble conflict.

As will soon become clear, our analysis of positive synergies is also intended to elucidate a fundamental quality of the marginal approach—myopia, or shortsightedness with regards to the prospects and implications of taking possible future combinations of precautions. The discussion here is therefore also meant to illustrate the differences between reviewing combinations of precautions the defendant could have taken in the past (unconstrained or semi-constrained analysis) and exploring different permutations of precautions the defendant would have been able to take in the future.

## **2) NORMATIVE REFLECTIONS: SUBOPTIMAL PRECAUTIONS AND MYOPIC COST-BENEFIT ANALYSIS**

Our first example illustrates distorted defendant's *ex-ante* incentives in the context of positive synergies and myopic cost-benefit algorithms. Consider the following setting:

Table 6: Positive Synergies, Suboptimal Precautions and Myopic Cost-Benefit Analysis

<b>Precaution Level</b>	<b>Cost</b>	<b>Risk (PL)</b>	<b>Risk Decrease</b>	<b>Social Cost</b>
<b>Actual</b>	10,000	50,000	--	60,000
<b>Lifeguards</b>	45,000	10,000	40,000	65,000
<b>Fence</b>	14,000	30,000	20,000	54,000
<b>Barricades</b>	10,000	30,000	20,000	50,000
<b>Signs</b>	1,000	25,000	25,000	36,000
<b>Fence + Barricades</b>	24,000	1,000	49,000	35,000
<b>Signs + Barricades</b>	11,000	22,000	28,000	43,000
<b>Signs + Fence</b>	15,000	22,000	28,000	47,000
<b>Fence + Barricades + Signs</b>	25,000	900	49,100	35,900

In this example, combining the fence with barricades generates a positive synergy, which increases their overall efficiency. While the fence alone reduces the risk by \$20,000, and barricades alone reduce the risk also by \$20,000, applying both precautions reduces the total risk by \$49,000, \$9,000 more than the sum reduction of both precautions individually.

It is not hard to think of reasons why such a positive synergy would occur in real life. For instance, it could be that some potential victims will only be willing to make the effort of walking by foot past barricades if they will not have to subsequently climb a fence, while other potential victims will only be willing to make the effort of climbing a fence if they will not have to walk past barricades to reach it. In other words, though some people would be willing

to climb a fence or pass barricades, almost no one would be willing to traverse past both.<sup>304</sup> Thus, in this example, barricades alone will reduce the number of potential victims by 40%, the fence alone will also reduce the number of potential victims also by 40%,<sup>305</sup> and the two positively synergetic precautions will reduce the number of potential victims by 98%.

The social optimum in Table 6 lies in building a fence and setting up barricades, as the overall gain derived from this strategy is superior to any other available course of action, including only posting signs ( $\$35,000 < \$36,000$ ). Signs remain cost-beneficial when taken alone, but are no longer part of the socially optimal set of precautions. In fact, if they are added to a combination of the fence and barricades, their addition is not cost-justified.<sup>306</sup> Under these settings, applying a marginal analysis might lead to suboptimal solutions. Specifically, it would incentivize potential defendants to post the socially suboptimal signs, as doing so would minimize their expected expenditure.

Figure IV.11: Positive Synergies, Suboptimal Precautions and Myopic Cost-Benefit Analysis, illustrates the defendant's *ex-ante* choices under a constrained marginal approach, using an extensive-form decision tree. We assume that lifeguards are mutually exclusive, and cannot be taken in conjunction with other precautions. The key features of this example are as follows:

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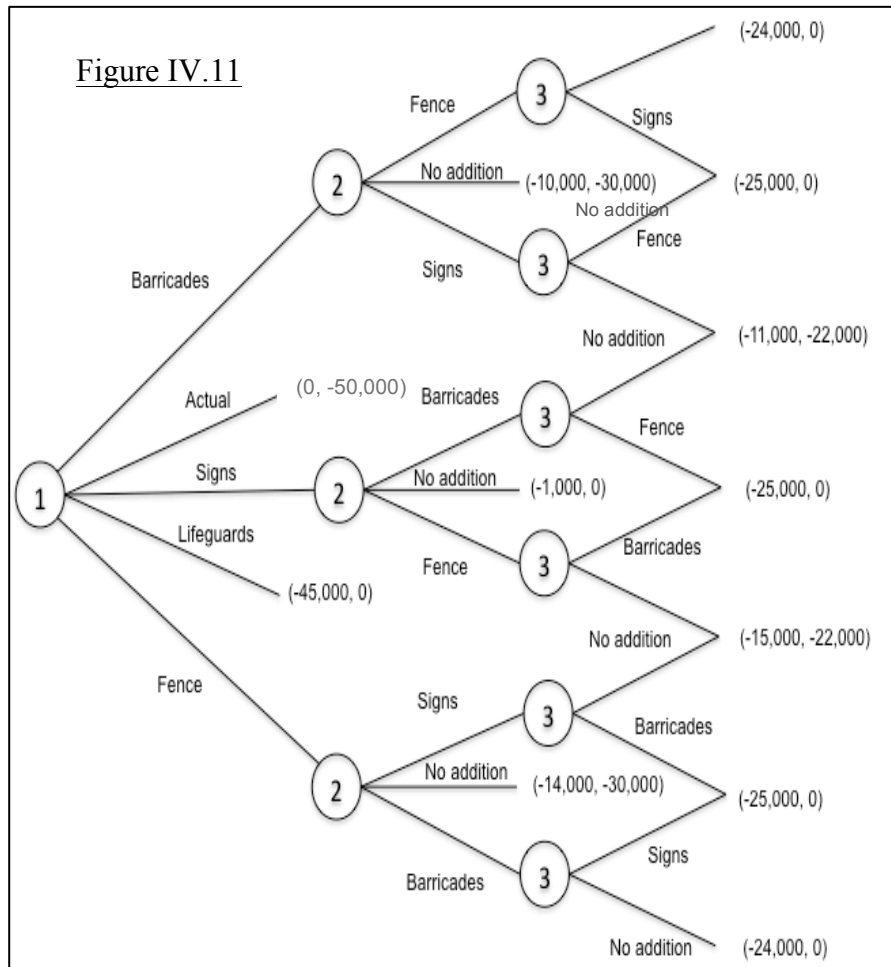
<sup>304</sup> This description reflects, in a sense, a threshold in the overall risk-reduction function.

<sup>305</sup> Obviously, these 40% of potential victims need not be the same 40% reduced by the barricades.

<sup>306</sup> Adding a benefit of \$900 at a price of \$1,000. The reduction in the marginal efficiency of signs can be attributed to overlaps.

First, taking the combination of a fence, barricades and signs would never result in finding the defendant negligent, as that combination reduces the expected harm to the defendant to a minimum.

Applying the socially optimal combination of barricades and fence would also not result in finding the defendant negligent on any breach of the tree, as the only possible addition to this combination, posting signs, is not cost-justified when added as a third precaution. Similarly, hiring lifeguards—



although inefficient—would not be considered negligent under a marginal approach, as no additional cost-justified precaution can be added to them.

Second, erecting barricades without adding a fence, or building a fence without erecting barricades, would always result in finding the defendant negligent. This conclusion is true for any stage of the game and at any arm of the decision tree. Due to the positive synergy between the fence and barricades, once either of them is built and subsequently considered a constraint,

the other precaution becomes marginally cost-justified, irrespective of other settings and precautions.

*Third*, posting signs as a first precaution, without adding any successive precautions, would result in finding the defendant not liable, as no single precaution can be efficiently added to signs when taken as a first precaution. Neither a fence nor barricades can be efficiently added to signs, as each of them would individually reduce the expected harm by 3,000 at a respective cost of \$14,000 and \$10,000. However, posting signs after barricades have been erected or a fence has been built would not affect the defendant's liability. After a fence is built, the defendant will be found liable unless he adds barricades to the fence. Conversely, after barricades are erected, the defendant will be found liable under a marginal analysis unless he adds a fence to the barricades. Whether signs are posted or not after barricades or a fence are built is therefore inconsequential from a liability perspective.<sup>307</sup>

The desirability and efficiency of signs is thus highly path-dependent: As a first precaution, they are marginally cost-justified, and would suffice for the defendant to avoid liability, in light of the limited forward-looking scope of the marginal approach. As a second precaution to barricades or fence, signs are marginally cost-justified, but will have no effect on the defendant's liability or the additional steps he would have to take in order to meet the standard of care. As a third precaution, signs are no longer cost-justified, due to overlaps with the fence and barricades.<sup>308</sup>

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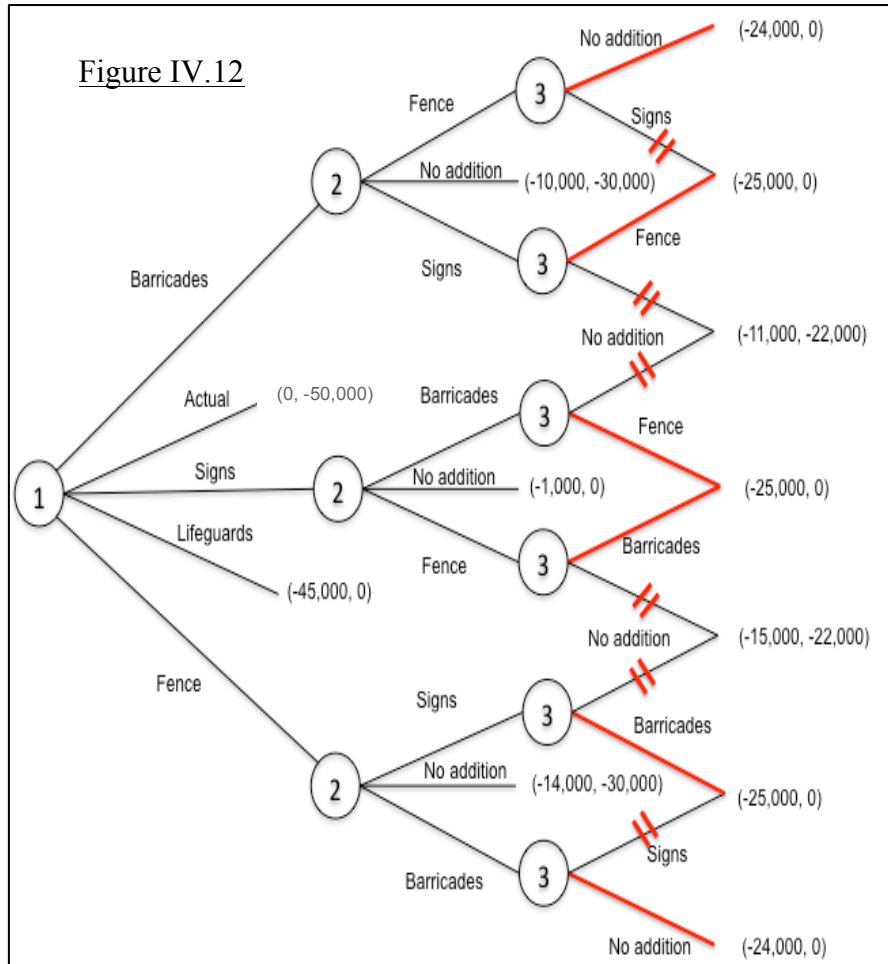
<sup>307</sup> As the conditions of this example make it, a fence is marginally cost-justified after barricades and signs have been taken, and barricades are marginally cost-justified after a fence and signs have been taken. For that reason, posting signs as a second precaution will have no impact on the defendant's overall liability.

<sup>308</sup> When signs are taken alone, they reduce the overall harm by \$25,000 at a cost of \$1,000. When they are posted as a second precaution after the fence or barricades, they reduce the overall harm by \$8,000 at a cost of \$1,000. As a third precaution, they reduce the expected harm by \$100 at a cost of \$1,000.



Figures IV.12-IV.13: Positive Synergies, Suboptimal Precautions and Myopic Cost-Benefit Analysis, demonstrate the solution to this setting, using retrograde analysis.

Beginning by folding the third level of the tree, Figure IV.12 illustrates that the defendant would always prefer building a fence after barricades have been erected in the first or second node ( $-24,000 / -25,000 > -33,000 > -40,000$ ), and would always prefer erecting barricades after a fence has been build in the first of second node ( $-24,000 / -25,000 > -37,000 > -44,000$ ). The defendant would also prefer not to add signs at any point after barricades or a fence have been built ( $-24,000 > -25,000$ ). The paths of the dominant strategies are marked in red.





exempted from liability, as signs are a superior course of action to both the fence and barricades individually,<sup>309</sup> and no single cost-justified precaution can be added to them.

The reason why both the marginal and alternative precaution not-taken approach fail to induce optimal results in this scenario goes back to a fundamental feature they share—myopathy. Both approaches are unable to consider hypothetical future permutations of precautions the defendant would be able to take, and focus instead only on a single (additional or alternative) change in current settings. Thus, while in previous examples we emphasized the tension between viewing short and long run analysis of previously taken actions, this example illustrates that a similar tension exists between a long and short run view of future options. Efficient incentive schemes might require not only an examination of multiple alternative combinations of precautions the defendant could have taken in the past, but also an exploration of multiple combinations he would be able to take in the future. In both cases, cost-benefit analysis in law must consciously adjust the number of degrees of freedom used in the analysis to accommodate for specific needs and problems. Indeed, legal investigation and review must be as sensitive, flexible and smart in gazing towards the future as in looking into the past.

### **3) NORMATIVE REFLECTIONS: INEFFICIENT PRECAUTIONS AND MYOPIC COST-BENEFIT ANALYSIS**

Positive synergies may result in even more disturbing outcomes when myopic cost-benefit algorithms are applied. This is especially true for settings where precautions are neither optimal nor cost-efficient when taken alone (such as lifeguards in Table 6), but are on the efficient or even optimal set when taken in conjunction with other precautions. The

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<sup>309</sup> Signs are more effective in reducing harm than barricades or the fence (\$25,000 > \$20,000), and do so at a lower cost (\$1,000 < \$10,000 < \$14,000).

repercussions of applying the marginal approach in these settings can include not only errors by courts in misstating the optimal set of precautions, but also in denying claims where the defendant could have efficiently prevented the harm, and has done nothing instead.

To see this, imagine a case where no precaution is cost-justified when taken alone, but taking a number of precautions in conjunction is efficient. In such a case, a myopic marginal analysis would lead to a judgment of no liability, even though the defendant could have efficiently reduced the risk by taking a combination of precautions. Table 7 illustrates such a case:

Table 7: Positive Synergies, Inefficient Precautions and Myopic Cost-Benefit Analysis

<b>Precaution Level</b>	<b>Cost</b>	<b>Risk (PL)</b>	<b>Risk Decrease</b>	<b>Social Cost</b>
<b>Actual</b>	10,000	50,000	--	60,000
<b>Lifeguards</b>	45,000	10,000	40,000	65,000
<b>Fence</b>	14,000	40,000	10,000	64,000
<b>Barricades</b>	10,000	45,000	5,000	65,000
<b>Signs</b>	1,000	49,500	500	60,500
<b>Fence + Barricades</b>	24,000	12,000	38,000	46,000
<b>Fence + Signs</b>	15,000	39,600	10,400	64,600
<b>Barricades + Signs</b>	11,000	44,600	5,4000	65,600
<b>Fence + Barricades + Signs</b>	25,000	11,900	38,100	46,900

In Table 7, none of the possible precautions is cost-efficient on its own. However, a positive synergy renders the combination of a fence and barricades cost-justified, and provides

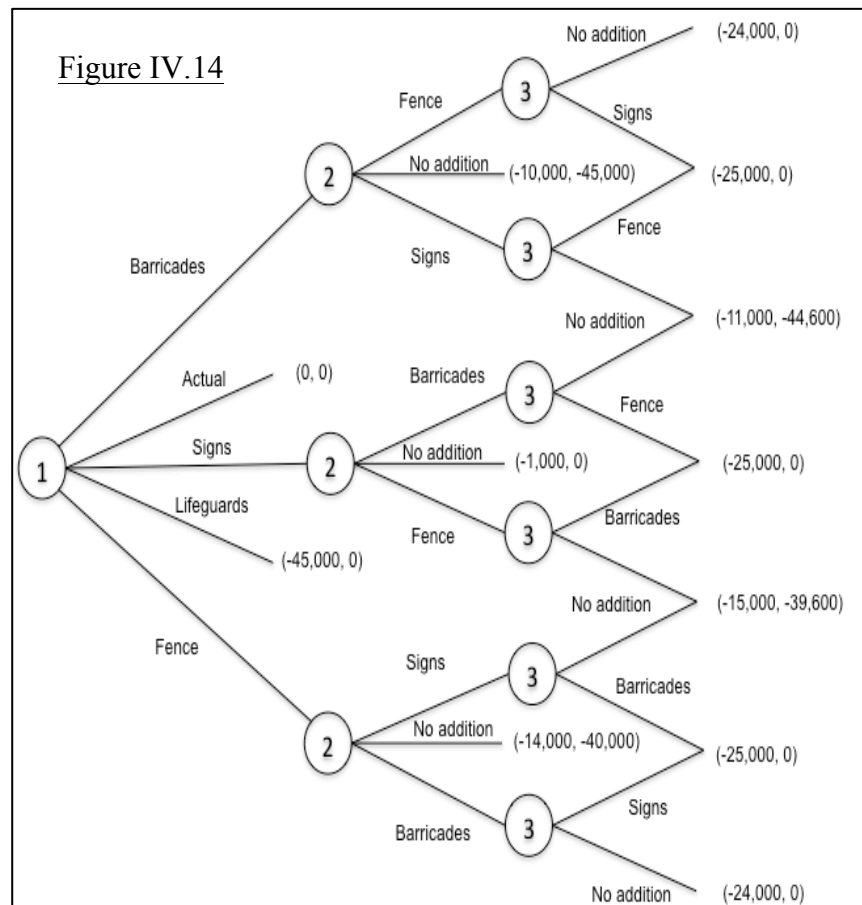
the socially optimal solution to this puzzle. As a result, if a court only compares the marginal efficiency of different precautions individually, it will arrive at the erroneous conclusion that no cost-efficient option was available to the defendant, and deny liability. When the marginal approach is applied in this highly myopic fashion to this case, not only will the prospective tortfeasor prefer to do nothing, but he will also attribute a negative value to taking either the fence or barricades, and would actually be willing to pay (“bribe”) third parties not to build one precaution without the other.

Figure IV.14: Positive Synergies, Inefficient Precautions and Myopic Cost-Benefit Analysis, illustrate the defendant’s *ex-ante* set of choices under Table 7, assuming the marginal approach is applied. As

with the above examples, the “actual” or previously taken level of care is considered sunk, and lifeguards are regarded mutually exclusive. To briefly summarize the key features of Figure IV.14:

*First*, taking the combination of barricades, fence and signs will not be

regarded negligent, as no cost-justified precaution can be added to it, and this combination reduces the overall risk to a minimum (\$11,900), but for the inefficient lifeguards. Taking the



socially optimal combination of barricades and the fence would also not result in negligence on any arm of the tree, as adding signs to this combination is not cost-justified. Additionally, hiring lifeguards would not result in a finding of negligence, as no additional cost-justified precaution can be added to them, and they produce the minimal risk to the plaintiff when compared to all other possible outcomes.

*Second*, as with our previous example, erecting barricades without adding a fence, or building a fence without adding barricades, would always result in finding the defendant negligent, due to the positive synergy between the fence and the barricades.

*Third*, posting signs as a first precaution, without adding a subsequent precaution, would absolve the defendant from liability, as no single cost-justified precaution can be added to signs. As with our previous example, if signs are added as a second or third precaution, they will have no impact on the defendant's liability, and their effect on the defendant's expected expenditure is highly path-dependent.

Figures IV.15-IV.16: Positive Synergies, Inefficient Precautions and Myopic Cost-Benefit Analysis, demonstrate the solution to this setting, using backward induction.

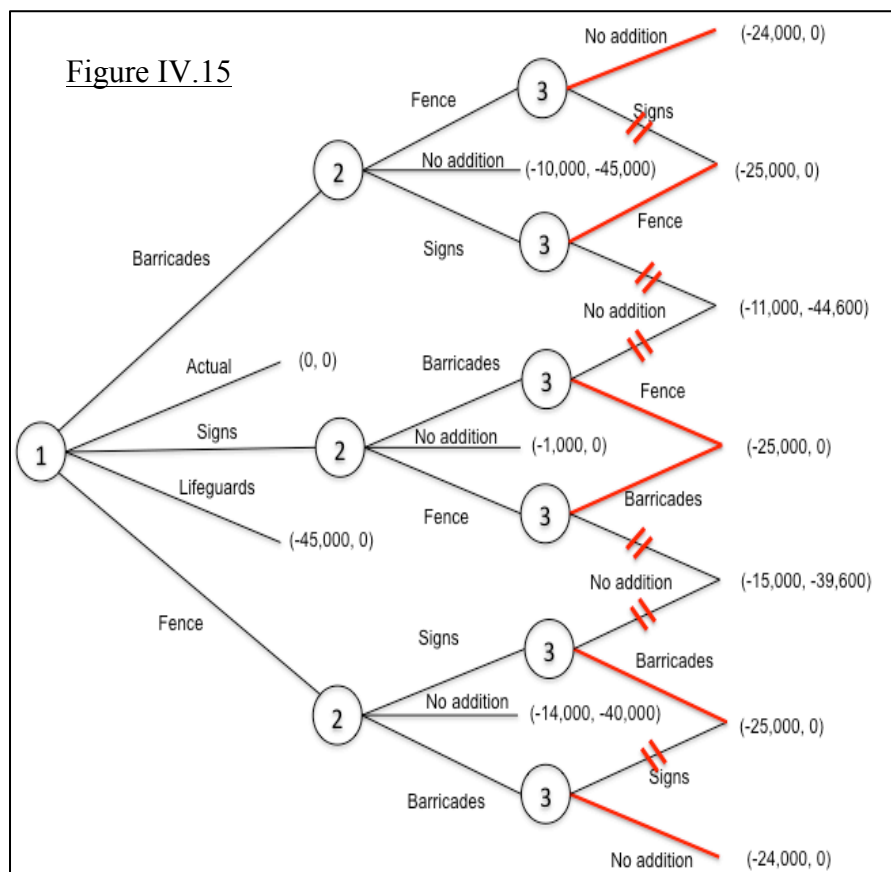
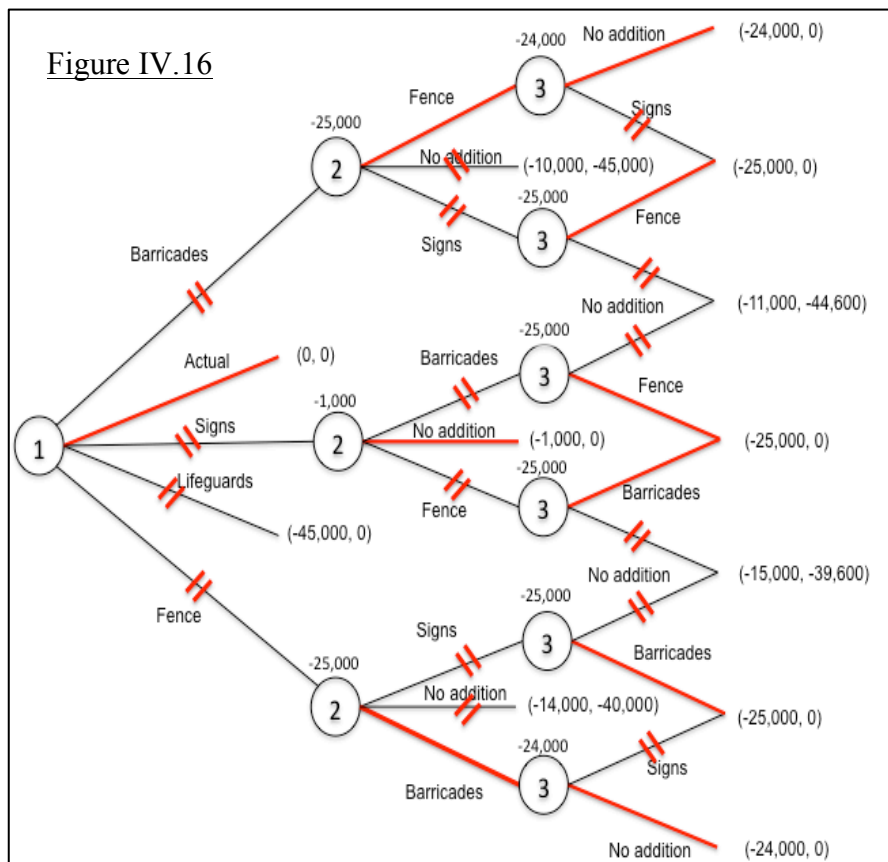


Figure IV.15 begins by folding the first level of the tree, and demonstrates the defendant's preference to build a fence if barricades have been erected in the past, and erect barricades if a fence has previously been build (as,  $-24,000 / -25,000 > -54,600 > -55,600$ ). It also demonstrates the defendant's preference not to add signs after either a fence or barricades are in place. The paths of the dominant strategies are marked in red.

Figure IV.16 completes folding the last two tiers of the tree, and demonstrate that the defendant's dominant strategy would be to do nothing, *i.e.* maintain his previous (sunk) level of

care, as that strategy would minimize his expected expenditure to zero. Knowing that the marginal approach would not sanction him for not taking any precaution (as no single precaution is cost-justified on it own), the defendant will have no incentive to invest in precautions, and would



actually place a negative value on barricades or the fence, as each would impose a duty to build the other. We can therefore conclude that applying a myopic marginal approach against the background of positive synergies might result in a finding of no liability, even when the defendant had a viable and cost-justified option to reduce the expected harm.

As with our previous example, the defendant's strategy would not change even if the court applied the semi-constrained alternative precaution not-taken approach, as none of the possible precautions in this example is cost-justified on its own. This result should not be surprising at this stage, as we have already noted that the root cause of inefficiency in the settings illustrated by Tables 6-7 is myopathy, not memoryless algorithms. Altering the set of constraints regarding past actions would not, therefore, have the desired effect in this case. To achieve efficient outcomes, let alone optimal incentives, lawmakers would have to review multiple degrees of freedom not only with regards to past taken actions, but also concerning future options.

#### **4) NORMATIVE REFLECTIONS: PAST OVERINVESTMENT IN INEFFICIENT PRECAUTIONS AND MEMORYLESS COST- BENEFIT ANALYSIS**

Our final discussion of positive synergies revisits the basic tension between constrained and unconstrained cost-benefit analyses in the context of past-taken precautions. Specifically, it illustrates conflicting incentives between short-run and long-run optimization when past miscalculations have been made and positive synergies take place. As we show, both the marginal and aggregated approaches might reach unsatisfactory and contradictory results in these settings, and bring a seemingly insoluble normative dilemma to surface.

Imagine a scenario where no cost-efficient precautions or sets of precautions are available to the defendant at time zero ( $T_0$ ). This is a simple case of unavoidable harm, where the defendant should not be considered in breach of duty for not taking any precautions or combination of precautions. Now assume that the defendant has taken an *inefficient*



precaution, not mandated by the duty of care, and as a result a subsequent or additional investment in precautions becomes cost-justified at time one ( $T_1$ ). Such a setup can occur often and for various reasons. Primarily, it may result from a positive synergy between the previously taken (inefficient) precaution and an untaken (also *ex-ante* inefficient) precaution. Additionally, as we have already explored in Part III, this setup may result from a threshold effect, particularly when an additional small investment can put a non-operational precaution into use, or is required to fix a malfunction in its operation.<sup>310</sup>

The reasons for taking the inefficient action at  $T_0$  are inconsequential. For our purposes here, we can simply assume that it was the result of an unexpected occurrence or a miscalculation. Miscalculations, all would agree, happen all the time. Table 8 illustrates such a case:

Table 8: Positive Synergies, Inefficient Precautions and Memoryless Cost-Benefit Analysis

<b>Precaution Level</b>	<b>Cost</b>	<b>Risk (PL)</b>	<b>Risk Decrease</b>	<b>Social Cost</b>
<b>Actual</b>	10,000	50,000	--	60,000
<b>Lifeguards</b>	55,000	10,000	40,000	75,000
<b>Fence</b>	34,000	30,000	20,000	74,000
<b>Barricades</b>	10,000	45,000	5,000	65,000
<b>Fence + Barricades</b>	44,000	7,000	43,000	61,000

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<sup>310</sup> To use our ongoing example, and as discussed in Part III, imagine a case where building a fence is inefficient and not required by the duty of care, but after a fence is built, mending a hole in the fence is cost-justified.

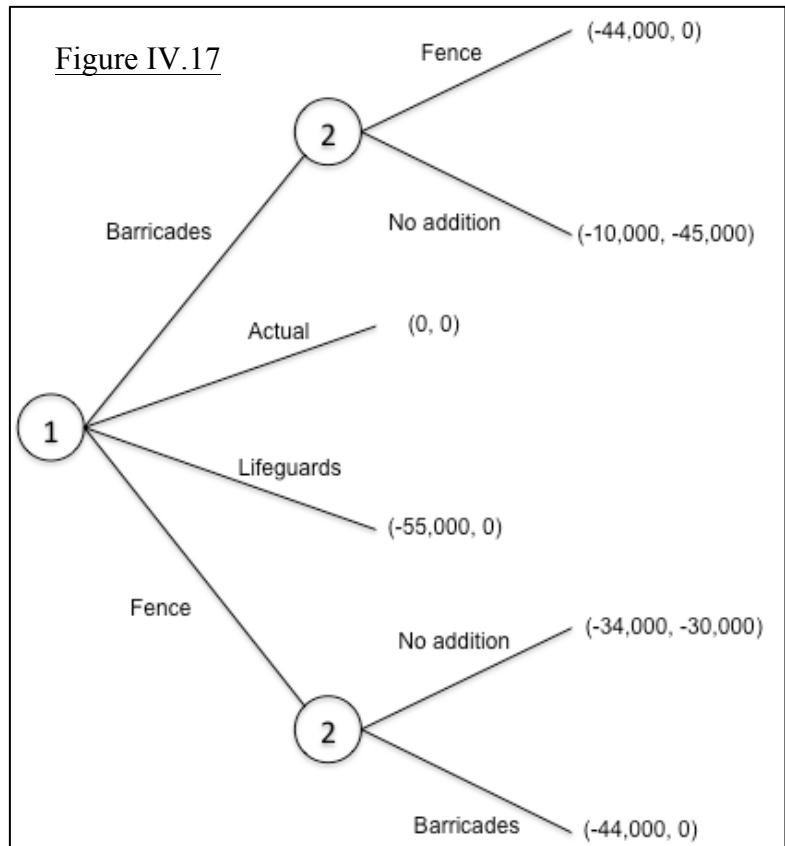
In Table 8, both the fence and barricades are inefficient on their own as well as in conjunction with one another, and their costs always exceeds their benefit. However, once a fence is built, adding barricades to it becomes incrementally cost-justified. To see this, notice that after a fence is built, investing an additional \$10,000 in setting up barricades will yield a benefit of \$23,000 ( $\$43,000 - \$20,000$ ). Similarly, once barricades are erected, adding a fence becomes cost-justified, as it will generate an additional benefit of \$38,000 ( $\$43,000 - \$5,000$ ) at a cost of \$34,000. This outcome results, in this case, from a positive synergy between the barricades and the fence.

The *ex-ante* social optimum for Table 8 lies in not taking any precaution, *i.e.* maintaining the “actual” level of care, as the social cost derived from this strategy is superior to any other available action, including the combination of building a fence and placing barricades ( $\$60,000 < \$61,000$ ). At  $T_0$ , therefore, both the marginal and aggregated approach would find the defendant not liable if he chooses to only maintain the preexisting level of care and not add additional precautions, as that strategy conforms with the (aggregated) duty of care, and no additional cost-justified marginal precaution can be added to it. However, if the defendant (erroneously and inefficiently) builds a fence, the marginal and aggregated approach will arrive at conflicting outcome at  $T_1$ . While the marginal approach would hold the defendant liable if he does not supplement the construction of the fence with barricades (as adding barricades to an already-constructed fence is incrementally cost-justified), the aggregated approach would not place such liability on a defendant, as owners of flooded mines are not required under the *ex-ante* duty of care to build a fence, set up barricades or do both in the first place. The fact that the defendant has already exceeded the prescribed and optimal *ex-ante* duty of care would not work to the defendant’s detriment under an aggregated analysis.

Figure IV.17: Positive Synergies, Inefficient Precautions and Memoryless Cost-Benefit Analysis, illustrates the defendant's *ex-ante* ( $T_0$ ) set of choices for Table 8, assuming the marginal approach is applied.

As with the above examples, the “actual” or previously taken level of care is considered sunk, and lifeguards are regarded mutually exclusive. The key features of Figure IV.17 are simple, and can be summarized as follows:

*First*, building a fence and setting up barricades will not result in finding the defendant



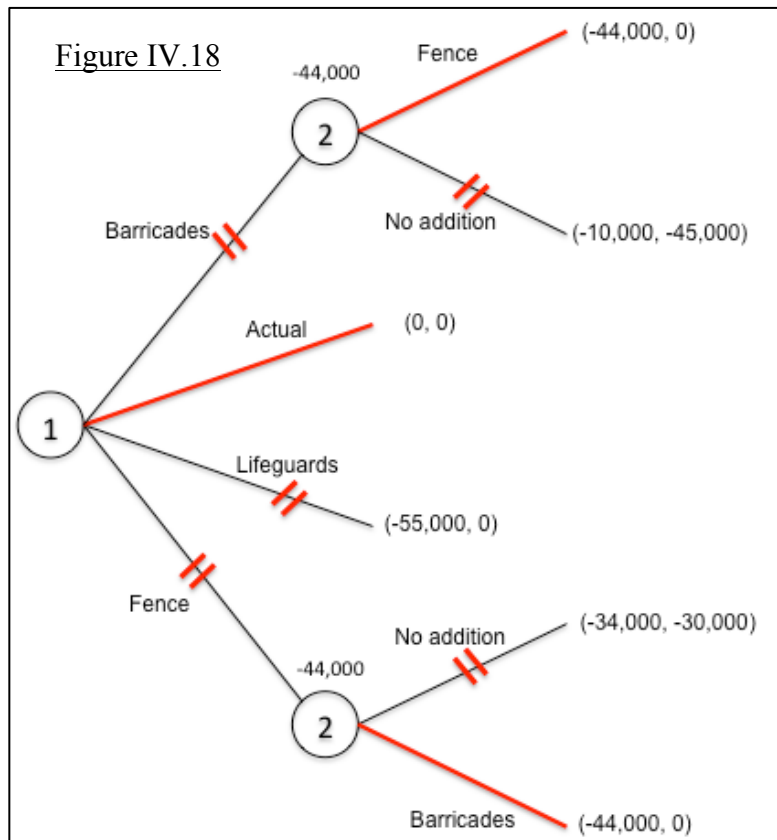
negligent, as that combination reduces the expected harm to the defendant to a minimum. Similarly, maintaining the preexisting (“actual”) level of care would net result in a liability finding, as doing so is the *ex-ante* social optimal strategy, and no precaution or set of precautions can be efficiently taken. Additionally, hiring lifeguards—although inefficient—would not be considered negligent, as it will reduce the expected risk by more than the socially optimal behavior, and no additional precaution can be added to them.

*Second*, erecting barricades without building a fence, and building a fence without erecting barricades, would result in finding the defendant negligent under a marginal analysis. In light of the positive synergy between the two precautions, once one of them is built and

subsequently considered a constraint, the other precaution would become marginally cost-justified and therefore mandated.

Figure IV.18: Positive Synergies, Inefficient Precautions and Memoryless Cost-Benefit Analysis, demonstrates and completes a retrograde analysis of this simple setting. Beginning

with folding the second tier, Figure IV.18 illustrates that the defendant would rather add a fence to existing barricades (as  $-44,000 > -55,000 > -64,000$ ). At the first decision point, the defendant would prefer to maintain the preexisting (“actual”) level of care, as that would minimize his expenditure to zero, and would not result in liability for the plaintiff’s harm ( $0 > -44,000 > -55,000$ ). The paths of the dominant strategies are again market in red.



Notice, that whether a marginal or aggregated approach is applied, the defendant should not reach node 2, which is not a subgame perfect equilibrium (or part of the *ex-ante* optimal set). If, however, the defendant finds himself in node 2, *i.e.* builds a fence or sets up barricades due to a miscalculation, he would prefer to add the second precaution if a marginal approach is applied, and would not add an additional precaution if an aggregated *ex-ante* standard is demonstrative.

Which is the preferable outcome or approach here? Recall that we have encountered almost the exact same setting before, in Section III.E.b.ii (discussion local minima postliminar to the global optimum in a single dimensional framework) and Section IV.B.f (discussing short-run versus long-run optimization in multidimensional frameworks). There, we explored whether it would be justified and efficient to require a defendant who has taken precautions beyond the socially optimal point to “go the extra mile” and increase his investment in care measures to the subsequent local minimum.<sup>311</sup> Our conclusion there, as in here, was indeterminate, and pointed to conflicted considerations associated with making this balance.

To quickly recap our discussion: On the one hand, the marginal approach seems justified here, at least from a short-run perspective, as it will induce efficient marginal investments (adding barricades to an already built fence, and *visé versa*). It would also follow conventional economic wisdom by excluding sunk-costs from cost-benefit analysis. Applying the aggregated approach would not achieve this result, and would therefore fail to induce efficient *ex-post* incentives. On the other hand, applying the marginal approach would place liability on a defendant who has gone above and beyond the socially accepted level of due care, might create an over-deterrence against taking certain precautions, and change the defendant’s *ex-ante* incentive scheme and decision-making patterns. The aggregated approach, however, does not suffer from these impediments. As we can see, therefore, the classic tension between short-run and long-run optimization in microeconomics is omnipresent in negligence law, and is a fundamental feature of the Hand Formula when applied outside the premise of the conventional model

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<sup>311</sup> Or the new global optimum, if all past settings are viewed as constraints.

#### **D. COMMENSURABILITY OF MULTIDIMENSIONAL FRAMEWORKS**

Is it at all possible, in light of our discussion in this part, to commensurate the range of achievable care as a function of investment in precaution along a single axis, as assumed by the conventional model? What are the necessary and sufficient conditions for doing so? Is such representation at all useful against the backdrop of multidimensional and interacting frameworks? The short answer to these questions is that commensuration to a single axis is generally possible, and can be made to mark the *ex-ante* technically efficient zone of possible (maximal) care, *i.e.* the limits of long-run safety production as a function of investment in precautions.<sup>312</sup> However, such a move would be little use for a system intently designed to apply an *ex-post* and myopic cost-benefit analysis, and at most can be used to set an abstract level of care in an aggregated context.

For any particular investment level ( $x_1$ ), the optimal *ex-ante* set of precautions can be of one composition  $\{P_a, P_b, P_c\}$ , while at the nearest incremental investment level ( $x_2$ ) the optimal *ex-ante* set of precautions can be unrelated,  $\{P_d, P_e, P_f\}$  or  $\{P_g\}$ , rather than  $\{P_a, P_b, P_c, P_d\}$ .<sup>313</sup> Stated differently, the optimal long-run set of precautions for investment level  $x_2$  does not necessarily have to consist of the same precautions optimal for investment level  $x_1$  plus an additional precaution.<sup>314</sup> Rather, the optimal set of precautions for investment level  $x_2$  can have little to nothing in common with the optimal set for investment level  $x_1$ , even though the two are extremely close. To give a concrete example, imagine a case where the optimal set of

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<sup>312</sup> For this term, in the context of conventional economic production theory see Besanko and Braeutigam, *Microeconomics*, *supra* note 211, at p. 186.

<sup>313</sup> Where  $P$  is a vector of all possible precautions,  $P_{1 \times m} = [p_i], i = 1, \dots, m$ , and  $x$  is a continuous variable representing the overall investment level in precaution. In this example,  $\{P_d, P_e, P_f\}$  might be the optimal solution for investment level  $x_2$  as a result of interactions, while  $\{P_g\}$  might be the optimal result due to a threshold effect.

<sup>314</sup> Or the application of a past-taken precaution at a higher level, assuming it is not binary.

precautions for an investment of \$99,999 ( $x_1$ ) is a fence and barricades, while the optimal set of precautions for an investment of \$100,000 ( $x_2$  or  $x_1 + \epsilon$ ) is lifeguards or another combination of precautions; rather than a fence, barricades and signs, or some other additional precaution.

Under these circumstances, a memoryless and myopic cost-benefit analysis obviously cannot guarantee long-run efficient solutions to optimization puzzles. This conclusion is true even if the marginal benefit from investing in *ex-ante* optimal bundles of precautions is decreasing and strictly convex.<sup>315</sup> To see the implications of this conclusion more clearly, consider a case where the defendant has already taken the optimal set of precautions for investment level  $x_1$ , and no additional precautions can efficiently be added to the already-taken bundle of precautions. In such a case, a memoryless marginal analysis would find that the defendant acted reasonably for not increasing his investment level to  $x_2$ , as no additional cost-justified precaution can be added. However, a broad-scope *ex-ante* analysis, unconfined by past constraints and sunk costs, might conclude that the defendant could have taken a superior and cost-justified set of different precautions at an investment level of  $x_2$ , and accordingly find the defendant negligent.

The probability of a memoryless short-run algorithm to optimally allocate precautions over the long-run seems, in fact, low, and is contingent on multiple assumptions and conditions. These conditions include, for instance, that, (i) the marginal efficiency of precautions is independent of and uncorrelated with past actions and omissions,<sup>316</sup> (ii) precautions are allocated based on their marginal efficiency, so that the most efficient marginal precaution is

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<sup>315</sup> In other words, (i) precautions are optimally allocated for each investment level, so that the costs of accidents cannot be reduced without increasing the overall investment level; (ii) the marginal benefit derived from investment in precautions is a strictly diminishing convex function.

<sup>316</sup> Or at least that such interactions do not take certain precautions out from the optimal set with any increase in investment level.

added at each point; (iii) optimal precautions sets along the efficient zone of care production are perfectly encompassing;<sup>317</sup> (iv) the marginal efficiency of precaution is a strictly downward-sloping function of investment in care; (v) the overall efficiency and cost functions do not manifest with threshold effects; (vi) lack of distortions associated with lumpiness; and more. In other words, commensurability along a single “investment level” axis, and equivalency of long and short-run analyses, are contingent upon the underlying assumptions of the conventional model, and must assume that precautions are taken in a manner conforming with the efficient zone of care production.

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<sup>317</sup> Meaning that the optimal set of precautions for each investment level  $[x_1, x_2, \dots, x_n]$  includes the optimal set of precautions for the previous investment levels, plus an additional one. Thus, for example, if the optimal set of precautions at investment level  $x_1$  is  $\{p_a\}$ , the optimal set of precautions at investment level  $x_2$  would be  $\{p_a, p_b\}$  and the optimal set of precautions at  $x_n$  would be  $\{p_a, p_b, \dots, p_n\}$ .



**PART V:**  
**ROADMAP TO A NEW MODEL OF COST-BENEFIT ANALYSIS IN  
NEGLIGENCE LAW: REFLECTIONS, PRINCIPLES AND GUIDELINES**

**A. INTRODUCTION AND GENERAL PRINCIPLES**

In previous parts, we attempted to rigorously outline the underlying assumptions of the conventional model, and unravel the various flaws and imperfections associated with the application of the marginal approach to setting where these assumptions are not met. Throughout our discussion, we demonstrated that the marginal approach might fail to create efficient incentives due to its fundamental features—past actions are always viewed as constraints, and the full extent of future possibilities are hardly considered at all. Additionally, we illustrated that the aggregated approach might also fail to induce efficient outcomes due to its own features—past actions are hardly ever viewed as constraints, and future options are contemplated in their totality. We further argued that these opposite failures reflect an irresolvable tension between short-run and long-run optimization processes, and found both approaches unfit as theoretical concepts, unsuitable as normative ideals and inapplicable in practice.

Our conclusion is therefore that the credence afforded to the marginal approach in conventional law and economic scholarship is unfounded, and cannot be earnestly defended. If we are to achieve efficient results in negligence adjudication, we cannot simply close our eyes, click our heels three times and whisper “marginal approach” or “diminishing marginal returns.” Faced with the inadequacies of both the marginal and aggregated analyses, a novel, realistic, flexible and comprehensive theory to negligence adjudication is needed. The following reflects

upon the general principles for such a new approach. While not intended as an overarching or exhaustive scheme, it devises a roadmap for its application.

In a nutshell, our claim is that the marginal and aggregated approaches merely represent two extreme ends of a wide spectrum, and a multitude of hybrid approaches to the application of the Hand Formula lie in between them. By altering various features of each approach, lawmakers can perform cost-benefit analysis in torts using different degrees of freedom, in a manner suited for the challenges presented by each case. While no single catchall or “cookie cutter” algorithm can efficiently optimize all real-world scenarios, specifically tailoring adjudication methods to the characteristics of each case, market and technology can substantially reduce the risks of strategic behavior and inefficiencies.

## **B. THE MANY FACES OF COST-BENEFIT ANALYSIS**

In any field, project, choice and human endeavor, from medicine to finance and from business to international relations, rational cost-benefit analyses can be performed using a variety of alternatives and methods. Some methods aim to optimize long-run over short-run benefits. Others assume that players are selfish, altruistic or employ a particular strategy. Some presuppose players act rationally, while others are designed to face behavioral biases. Some methods assume dynamic or stochastic settings, while others assume static and predictable environments. Yet additional methods attempt to maximize certain types of benefits, or optimize results on different plains of reference, while others assume all benefits are commensurable. Some methods are tailored to perfectly optimize scenarios characterized by uncorrelated, continuous, monotonically convex and single-dimensional variables, while

others are best suited to evaluate interacting, discontinuous, multidimensional or threshold settings.

Cost-benefit analysis in law is no different. In many legal fields, parties and lawmakers constantly face intricate optimization puzzles, and must choose a particular balancing or optimization method to resolve them. Such choices—even made unknowingly—necessarily reflect and vindicate certain values and preferences over others.<sup>318</sup> In other words, value judgments in law are made not only by assigning weights to different claims, but also by choosing between different types of scales and optimization methods, and by deciding which variables would be considered probative. The type of cost-benefit analysis algorithm used by lawmakers is as meaningful, demonstrative and values-driven—indeed often more so—as assigning numerical values to claims, risks and harms.

Evaluation methods differ not only with respect to the values they reflect; they also differ from an efficiency perspective. No one cost-benefit method is perfectly suited to optimize all real-life scenarios. Just as in medicine, there are no miracle drugs guaranteeing optimal results or cures for all diseases; and every prescription has possible adverse side effects. A particular cost-benefit algorithm may lead to efficient results in one type of case, but fail to do so in another. Legal cost-benefit analysis must therefore be tailored to the specific characteristics of each case type. Consistently and predictably utilizing one algorithm or cost-benefit method for every circumstance is likely to lead to inefficient or suboptimal results, and incentivize value-destroying strategic behavior by sophisticated players.

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<sup>318</sup> See Ronald Dworkin, TAKING RIGHTS SERIOUSLY 278-280 (1977). See also Stephen R. Perry, *Responsibility for Outcomes, Risks, and the Law of Torts*, in PHILOSOPHY AND THE LAW OF TORTS (Gerald Postema ed., 2001); and Green, *Negligence = Economic Efficiency: Doubt >*, *supra* note 15, at p. 1643.

### C. MIXED APPROACHES IN NEGLIGENCE LAW

In negligence law, cost benefit analysis may be conducted using multiple variants of the Hand Formula. By changing such factors as the past and future timespan considered or the type and number of conjunctive alternative hypotheticals to be taken into account, lawmakers can alter the way in which negligence analysis is performed and adjust it to relevant needs, circumstances, markets and cost and efficiency functions. I refer to these variants of the Hand Formula as “mixed approaches”, as they incorporate elements of both the aggregated and marginal approaches on a temporal scale.

The marginal and aggregated approaches are, in fact, merely extreme ends of a broad spectrum, and a multitude of mixed approaches lie between them. For instance, instead of an entirely-constrained marginal analysis, a court may employ the abovementioned semi-constrained alternative precaution not-taken method, which considers not only marginal omissions, but also one possible alternative the defendant could have taken instead of an action actually taken. The court may also resolve to review two alternative changes, and consider hypothetical outcomes that could have resulted had the defendant altered two past actions or omissions. By the same logic, any number of precautionary “bundles” or conjunctive alternative hypotheticals can be compared and reviewed.

The number of possible alternatives or steps jointly contemplated can be expanded or limited not only with regards to past actions or omissions, but also with respect to future possibilities. For instance, a court may limit itself to explore the possible effect of adding a single precaution not-taken (as prescribed by the marginal approach), an unlimited number of additional precautions (as the aggregated approach purports to do) or any number between them. For continuous precautions, lawmakers can equally decide upon the “width” or level of

future additions or past alterations reviewed, and replace the marginal incremental method for an expansive exploration of non-marginal additions or changes in precaution levels.<sup>319</sup>

We can refer to the number of alterations and future additions contemplated in the application of Hand Formula as the number of “degrees of freedom.” Thus, for example, the marginal approach does not allow for any freedom in its review of the past (*i.e.* it is wholly constrained, or memoryless), and permits a review of only a single additional precaution not-taken (*i.e.*, it is myopic). The alternative precaution not-taken approach, by contrast, allows for one degree of freedom with regards to past-action. In much the same way, the number of degrees of freedom with regards to past and future precautionary bundles can be set at any number, creating an endless variety of possible cost-benefit algorithms. As negligence analysis is performed using more and more degrees of freedom, the number of permutations comprising of future additions and past alterations naturally increases, and the level of complexity and possible hypothetical scenarios grows exponentially.

Mixed approaches differ, however, not only with respect to the number of degrees of freedom they permit—they can vary in assorted other manners as well. In addition to altering the number of degrees of freedom, different cost-benefit analysis methods can be crafted by (i) limiting or expanding the timespan in which a plaintiff is allowed to claim the defendant acted negligently;<sup>320</sup> (ii) limiting or expanding the number of precautionary “step-backs”

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<sup>319</sup> Green made a somewhat related claim from the perspective of a marginal analysis, noting that “[h]aving made the comparison-at-the-margin point, we should understand that there is nothing inherent in risk-benefit about how wide the margins should be. We might employ rather narrow margin by employing a relatively modest additional precaution.... [or] [t]he margin might be wider... The ultimate marginal comparison entails a comparison of all the risks of the product with all of its benefits.” (Green, *Negligence = Economic Efficiency: Doubt >*, *supra* note 15, at p. 1613). However, this rare note only pertains to the future scope of the marginal analysis is single-dimensional frameworks, and is highly limited in its nature. Green’s analysis does not relax the underlying assumptions of the conventional model, not does it address the difficulties presented in this thesis.

<sup>320</sup> The statute of limitation and the statute of repose are prime examples of this, as discussed in Part IV. On the common law’s approach different time periods within the context of bilateral precautions see Mark F. Grady, *Common*

allowed in the review of sequential settings;<sup>321</sup> (iii) adjusting the measuring scales used to evaluate the defendant's behavior;<sup>322</sup> (iv) selecting which variables would be considered exogenous or endogenous to negligence analysis;<sup>323</sup> (v) altering the level of generalization taken in performing negligence analysis;<sup>324</sup> (vi) taking account of objective, subjective or objective-subjective costs and benefits in the implementation of the Hand Formula; (vii) prioritizing long-run or short-run incentive schemes; (viii) treating players as rational, irrational or recognizing certain behavioral biases;<sup>325</sup> (ix) considering the defendant's motives and strategic aims as pertinent to the analysis;<sup>326</sup> and so forth. Together with the number of degrees of freedom, these factors operate to set the overall level of complexity to be considered by the court, and define the particular mixed approach implemented.

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*Law Control of Strategic Behavior: Railroad Sparks and the Farmer*, 17 J. LEGAL STUD. 15 (1988).

<sup>321</sup> By step-backs, we mean the maximum number of past-taken precautions that would be considered variables rather than constraints. The term is closely related to past timespan in sequential settings. When the setting is not sequential, we can equate the number of step-backs to degrees of freedom. For a suggestion to review past taken precautions in bilateral settings see Guttel, *The (Hidden) Risk of Opportunistic Precautions*, *supra* note 39, at p. 1415.

<sup>322</sup> The same behavior may or may not be considered negligent when reviewed through different scales and lenses. For example, as we have already discussed, the average speed of a car over one timeframe might be considered negligent, while the average speed as measured against a different timeframe might not. For temporal framing problems see also Douglas Husak and Brian P. McLaughlin, *Time-Frames, Voluntary Acts, and Strict Liability*, 12 LAW & PHIL. 95 (1993); and Shawn J. Bayern, *The Limits of Formal Economics in Tort Law: The Puzzle of Negligence*, *supra* note 21.

<sup>323</sup> As discussed in Part IV. For a similar notion regarding variable selection, in the context of temporal continuums and bilateral precautions see Anderson, *The Missing Theory of Variable Selection*, *supra* note 22 (reflecting on the choice between liability regimes and different aspects of tort law, such as the division between negligence and strict liability, contributory negligence, causation, last clear chance, assumption of risk, mitigating damages and cheapest-cost-avoider).

<sup>324</sup> On different levels of generalization, see Guido Calabresi and Jon T. Hirschoff, *Towards a Test for Strict Liability in Torts*, 81 YALE L.J. 1054 (1972) (hereinafter: "*Towards a Test for Strict Liability in Torts*") (discussing levels of generalization within the context of cheapest-cost-avoider); Gilles, *Rule-based Negligence and the Regulation of Activity Levels*, *supra* note 21, at 319; and Anderson, *ibid*, at pp. 272-274.

<sup>325</sup> See, for instance, Gary T. Schwartz, *Reality in the Economic Analysis of Tort Law: Does Tort Law Really Deter?*, 42 UCLA L. REV. 377 (1994); and Christine Jolls, Cass R. Sunstein and Richard Thaler, *A Behavioral Approach to Law and Economics*, 50 STAN. L. REV. 1471 (1998).

<sup>326</sup> Considering individual motivations might entail both practical and normative difficulties, and is generally considered outside the scope of negligence inquiry. For a claim that court have been able to "successfully prevent willful, inefficient costs shifting" bilateral precaution settings and nuisance cases see Guttel, *The (Hidden) Risk of Opportunistic Precautions*, *supra* note 39, at p. 1420, and the cases cited on footnote 68-75 there. See also, Grady, *Multiple Tortfeasors and the Economy of Prevention*, *supra* note 95.

The number of possible algorithms or mixed approaches resulting from these alterations is truly boundless. For instance, reflect upon the different combinations ensuing from merely varying the number of degrees of freedom and the permitted number of step-backs in sequential settings (or length of past timespan). If no step-backs are allowed (*i.e.* all sequential past-taken precautions are considered constraints), and the hypothetical impact of only one additional precaution is examined, the marginal approach is applied. If one degree of freedom and one step-back are allowed, a (memoryless and myopic) alternative precaution not-taken approach is applied, which will only question whether the defendant could have taken a superior precaution on his last move in a sequential setting. Similarly, lawmakers can apply an alternative precaution not-taken approach using any other number of step-backs. For instance, an analysis providing for one degree of freedom and two step-backs would question whether the defendant could have taken a single superior alternative in any of his last two moves. An analysis providing one degree of freedom and no limit on the number of step-backs would question whether the defendant could have taken a single superior precaution at any time or step in the past (“myopic precaution not-taken approach”), and so forth.

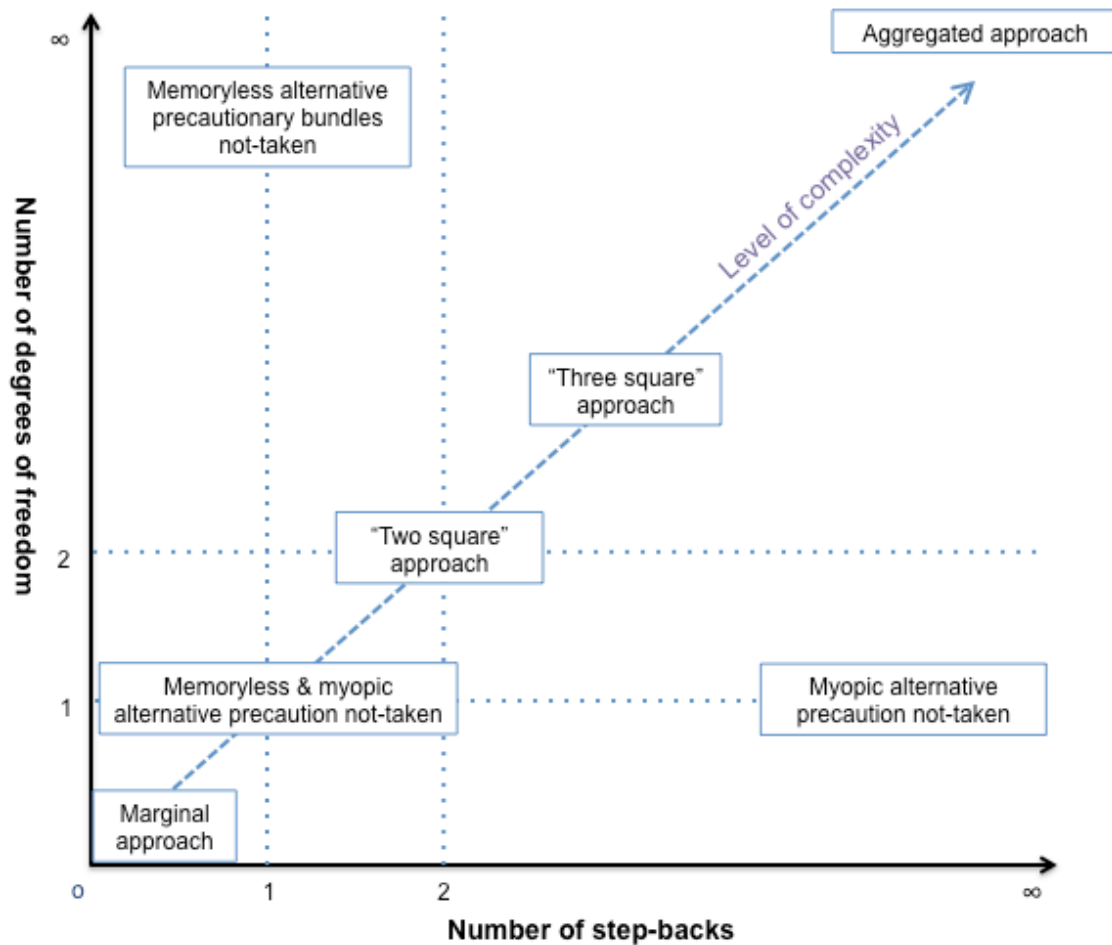
When the number of degrees of freedom is also altered, additional algorithms can be crafted. For instance, an approach allowing for two degrees of freedom and two step-backs would explore the hypothetical impact of altering or adding no more than two precautions, but would consider all past actions as constraints except for the last two (a “two square” approach). An analysis allowing for unlimited degrees of freedom and one step-back would question whether any additional or alternative precautionary bundles would have yielded a superior outcome, but would consider all but the last precaution taken as constraints (a “memoryless alternative precautionary bundles not-taken” approach). An analysis allowing for unlimited

degrees of freedom and unlimited step-backs would question whether adding or altering any number of precautions would have yielded a superior outcome, *de-facto* applying an aggregated analysis, and so forth.

As the number of degrees of freedom and permitted step-backs increases, the resulting cost-benefit analysis method would be better equipped to handle intricate and knotty settings characterized by multiple moving parts and sequential evolution, but will also become more complex and difficult to implement, and might prioritize long-run goals over short-run incentives. Figure V.1 illustrates the various cost-benefit analysis methods resulting from altering the number of degrees of freedom and permitted step-backs, as well as the increasing complexity of these methods. It points to the marginal approach on one end, and to the aggregated approach on the other. Similar illustrations can be made to reflect methods resulting from alterations of other factors affecting the nature of cost-benefit analysis methods.



Figure V.1: Overall Complexity of Different Types of Cost-Benefit Analysis Methods



This richness of possibilities within negligence law has, generally speaking, eluded tort economic scholarship. The conventional model's focus on the marginal approach has, in this sense, done a great disservice to our understanding of the complexity of cost-benefit optimization methods, the innate limitations they presents, the values and aims they reflect and the various possibilities to strategically manipulate negligence adjudication in the courtroom. More than everything, the limited scope and confining assumptions adhered to in economic literature have obscured the need to tailor cost-benefit analysis methods to the specific characteristic of changing markets, technologies and players, and to the ever-pressing need to

perform targeted legal-empirical research on the specific cost and efficiency functions of each field.

#### **D. THE TAILORING PRINCIPLE AND THE IMPOSSIBILITY THEOREM**

Our above discussion sought to lay the foundations for two general principles: *First*, that no single variant of the Hand Formula is perfectly suited to optimize all real-world scenarios, and all such variants might fail to achieve their goals as a result of interactions, threshold effects, discontinuities, non monotonically convex efficiency functions and the innate tension between long-run and short-run optimization. We can refer to this as the impossibility theorem. *Second*, that the efficiency goals of negligence law can only be achieved—if at all—by specifically tailoring an adjudication method to the unique characteristics of each setting, market and technology, and relying on strong empirical footings. We can refer to this as the tailoring or adaptation principle.

Each type of mixed approach is best suited to optimize a particular setting, and no one approach is suited to all circumstances. For instance, as this dissertation demonstrated, the marginal approach is principally suited for single continuous precautions abiding by the rule of diminishing marginal returns. When precautions interact, present with non monotonically convex efficiency functions or temporal changes occur, applying the marginal approach might lead to various inefficiencies. Similarly, the alternative precaution not-taken approach is suited to optimize cases where a single alternative precaution is possible. When multiple conjunctive alternatives exist, this method is also likely to fail. The aggregated approach might avoid some of the above problems, but is clearly inapplicable, and in any case might lead to different

inefficiencies associated with sunk costs, administrative costs and inefficient short-run incentives.

This outcome presents with an intriguing puzzle, which accompanied our discussion throughout Parts III and IV. On the one hand, the more deference is granted to marginal actions and omissions, the more the analysis might lead to inefficiencies and incentivize value-destroying strategic behaviors, mended only by a broad-scope analysis of past actions and future options. This is the case where, for example, considering previously taken precautions as constraints would induce a defendant to make suboptimal or even inefficient investments at  $T_1$ , knowing that as a result no additional cost-justified precautions would be available to him at  $T_2$ . On the other hand, the more deference is given to broad-scope and long-run considerations, the more the analysis might induce inefficient short-run behaviors, and in any case the informational costs associated with it are might not be justified. This is the case where, for example, not viewing previously taken actions as constraints would fail to induce a defendant who has overinvested or underinvested in precautions at  $T_1$  to take additional cost-justified precautions at  $T_2$ .

More generally, the marginal and aggregated approaches, and the various mixed approaches between them, reflect an innate and irreconcilable tension between short-run and long-run optimization, whereby inducing long-run efficient behavior might hinder short-run efficient incentives, and *vice versa*. Taking any action—optimal, suboptimal, inefficient underinvestment or inefficient overinvestment—inherently transforms past variables into constants simultaneously with introducing new possible alternatives and options. As a result, optimization puzzles in torts often present with contradictory considerations between short and

long run incentives and between *ex-ante* and *ex-post* motivations. Anderson made a partially similar argument from the perspective of variable selection in *bilateral* settings, noting:

“...[T]ort law faces competing and sometimes irreconcilable goals to optimize in the short and in the long run. A liability test that includes every accident-reducing input might be efficient in the long run but will provide little incentive for subsequent actors to minimize accident costs once negligence has occurred.”<sup>327</sup>

To some degree, all mixed approaches suffer from comparable weaknesses, and might fail to achieve optimal results due to misreading the nature of the relevant cost and efficiency functions or the double-edged sword of short-run versus long-run incentives. No matter how many degrees of freedom are permitted and how complex the approach, the inescapable fact is that any alteration or movement on the scale between the marginal and aggregated approach would entail both favorable and unfavorable results. Long-run mixed approaches are always prone to induce inefficient marginal actions, but are less likely to be manipulated by a defendant’s past strategic choices. Short-run mixed approaches are more likely to induce efficient marginal behaviors and ignore sunk costs, but are always prone to strategic manipulations. These conflicting constraints cannot be perfectly and systematically accommodated. In that respect, I believe Anderson correctly noted that “no satisfactory general theory is possible” to the applications of the Hand Formula, and that “the economic analysis of tort law provides indeterminate prescriptions” as a result.<sup>328</sup>

The Hand Formula—or perhaps better phrased “Hand Formulas”—must therefore be reconceived as a general optimization framework, not a one-size-fits-all solution or algorithm.

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<sup>327</sup> Anderson, *The Missing Theory of Variable Selection*, *supra* note 22, at pp. 256, 264 (focusing on variable selection and choice between different liability regimes in bilateral precaution settings, without discussing the various concerns and possible inefficiencies contemplated in this thesis).

<sup>328</sup> Anderson, *ibid*, at p. 255.

It ought to be thought of as a general scheme for minimizing accident costs under a negligence regime, and applied in a manner specifically tailored to the characteristics the relevant markets, technologies and settings.<sup>329</sup> As a central element, a court must be mindful of the type of interactions, cost and efficiency functions prevalent in each case, and give thought to the type of balancing formula that should be applied. Additional relevant elements include the possibility of *ex-ante* strategic manipulations, whether the parties are repeated players and sophisticated, the prevalence of cases of the same sort,<sup>330</sup> the stakes involved and more. When no such tailoring takes place, and only one variant of the Hand Formula is consistently and predictably applied, inefficient results and strategic behaviors are likely to follow.

Negligence adjudication therefore requires a flexible, sensitive approach, specifically tailored to the characteristics of every case. It cannot exclusively rely on a single catchall or “cookie-cutter” approach if it is to reach efficient outcomes, and must remain attentive of changes in costs and efficiency functions. Only by carefully applying tailored solutions, coupled with reliance on empirical information and theoretical projection, can negligence law come closer to providing efficient incentives and disable regulatory regimes.<sup>331</sup>

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<sup>329</sup> Compare Richard W. Wright, *The Standard of Care in Negligence Law*, in PHILOSOPHICAL FOUNDATIONS OF TORT LAW 249 (David G. Owen ed., 1995).

<sup>330</sup> Compare, Landes and Posner, *Legal Precedent: A Theoretical and Empirical Analysis*, *supra* note 57; and Cooter, Kornhauser and Lane, *Liability Rules, Limited Information, and the Role of Precedent*, *supra* note 57.

<sup>331</sup> For the general claim that liability regimes should correspond with the specific economic structure of accident situation see Calabresi, *The Cost of Accidents*, *supra* note 9, at pp. 140-141. See also our discussion of empirical settings in Part III above and in Anderson, *The Missing Theory of Variable Selection*, *supra* note 22, at p. 258. For a different classification of the negligence test, and related policy concerns see Ariel Porat, *The Many Faces of Negligence*, *supra* note 90.

## **E. OPTIMIZATION COSTS AND THE PLEADING SYSTEM**

The decision of which optimization method to apply, and which variables to take into account, must also consider a second order condition—the costs of the optimization process itself, not only its impact on the efficiency of the outcome.<sup>332</sup> Some methods are cheaper to implement than others. Some are so expensive or complicated as to almost always make them unjustified. Generally speaking, the cost of optimization is augmented as more degrees of freedom are used and a longer timespan is considered, as the underlying technology becomes more complex, as the level of generality explored increases and as actions or omission become less observable and verifiable.

Deciding between different forms of negligence review therefore necessitates—in and of itself—a cost-benefit evaluation. Such evaluation should take into account information or decision-making costs on the one hand, and the costs of inefficient and suboptimal judgments on the other. The higher the stakes, rewards and risks of strategic behaviors, the more the court ought to go beyond a simple marginal analysis. The higher the costs of information and judicial review, the more reasonable it would be for a court to limit the number of degrees of freedom and defer to a straightforward method.<sup>333</sup>

In practice, the litigants themselves heavily influence the number of degrees of freedom the court is likely to consider through the common law pleading system. As the adversarial

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<sup>332</sup> Compare, Louis Kaplow, *A Model of the Optimal Complexity of Legal Rules*, 111 J. L. ECON. ORG. 150 (1995).

<sup>333</sup> Anderson, following Calabresi and Hirschoff, viewed this dilemma somewhat differently, suggesting a general correlation between the level of generality applied by different legal regimes and the temporal scope of the analysis (“negligence tests in general are used at a low level of generality and in the short run. Courts have to learn an enormous amount about the possible range of precautions the defendant could have taken, in order to decide whether or not the precautions they did take were justified. This requires a great deal of information. Courts economize by taken many things as given, and ignoring long-run precautions, such as activity levels.” Anderson, *The Missing Theory of Variable Selection*, *supra* note 22, at p. 274). See also Calabresi and Hirschoff, *Towards a Test for Strict Liability in Torts*, *supra* note 324.

process is predicated upon parties' control over the claims argued before the court, the nature and complexity of negligence analysis is profoundly influenced by the wills and wants of the litigants. As Grady phrased it:

“Events do not define what negligence analysis will be the case, and the court does not define it either. Instead, by selecting an untaken precaution on which to rely, the plaintiff defines the analysis that everyone else will use...”<sup>334</sup>

Similarly, the RESTATEMENT (THIRD) OF TORTS states:

“At trial, the plaintiff who alleges the defendant's negligence normally bears the burden, first, of describing the defendant's conduct, and second, of identifying the precaution or precautions the defendant should have adopted.”<sup>335</sup>

We can assume that plaintiffs' willingness to plead in a manner requiring more elaborate forms of analysis is proportionate to the stakes involved. When the expected rewards to plaintiffs are low, it is less likely that they will be willing to incur the costs associated with a complex in-depth analysis. Conversely, when the expected rewards are high, the more likely it is that plaintiffs will invest in expensive measures and acquire the needed information to prove negligence by a more comprehensive inquiry.<sup>336</sup>

Conceivably, therefore, negligence adjudication is fundamentally different between high and low-stake tort cases. It is not only that deep-pocket litigants engaged in high-value

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<sup>334</sup> Grady, *Untaken Precautions*, *supra* note 18. Recall that Grady focuses only on single (marginal) untaken precautions, and adheres to the marginal approach.

<sup>335</sup> And continuing to state, “Assigning this second burden to the plaintiff is not always ideal, since the defendant may have better access to information about the relevant safety options and technology. Nevertheless, the assignment seems necessary, given the impracticality of requiring the defendant to prove a negative—the absence of any reasonable precautions.” (RESTATEMENT (THIRD) OF TORTS: PHYS. & EMOT. HARM § 3 (2010), *Comment h*).

<sup>336</sup> Furthermore, litigants' control over claims presented to court allows them, to some degree, to “reframe” events to fit their individual needs and claims. Thus, they may alternate between a short and long run review or present data using different scales and modes of analysis, limiting a court's ability to apply only a marginal analysis.

disputes utilize more experienced lawyers or invest more in evidence gathering. It is also that high-stake cases allow for more convoluted hypotheticals to be considered and a longer timespan to be taken into account in applying the reasonableness standard. While a slip-and-fall case is likely to be weighed based solely on a straightforward marginal analysis, a pharmaceutical drug recall is likely to be adjudicated utilizing far more degrees of freedom and an in-depth review of past-actions. The complexity of negligence adjudication is, consequently, theoretically and practically correlated with the potential gains from any particular case.<sup>337</sup>

This outcome, that high-stake defendants are subject to higher scrutiny than low-stake defendants, may seem problematic. It certainly invites a debate from a wide perspective, particularly from a justice standpoint, and further serves to show the fragmented nature of the Hand Formula. The notion that different standards of review are afforded to different types of litigants and cases certainly entails disturbing elements. Yet, it should not be all that surprising. The legal system regularly handles low and high stake cases differently. For instance, our rules of subject matter jurisdiction ordinarily grant higher, more experienced courts, jurisdiction over high-stake cases, while low-stake plaintiff argue their case before a lower court.

Putting aside possible criticisms pertaining to justice and equality for a moment, differences in standards between litigants could be, I believe, efficient. High stake cases are usually complicated, and involve multiple working-components and cutting-edge technology. Misjudging the adequate level of care in these cases might entail far more severe risks and adverse repercussions. They are also often rather unique, and present new and unexplored

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<sup>337</sup> This result bears a strong resemblance to the different standards applied in ordinary negligence and product liability. See, for instance, Guido Calabresi and Alvin K. Klevorick, *Four Tests for Liability in Torts*, 14 J. LEGAL STUD. 585 (1985).



changeless to the court. As a result, high-stake cases innately require an in-depth adjudication process that is not merited in most other cases. While adjudicating a deepwater oil spill in the Gulf of Mexico would require an extensive and creative review of past actions, alternative technologies, alternative bundles of care, policy considerations, regulation, procedures, different levels of generalization and so forth, a slip-and-fall case usually hinges on the defendant's marginal and short-term omission, and can be decided based on the defendant's answer to a few simple questions.

More importantly, high-stake prospective defendants are more likely to be sophisticated, rational and strategic. They are therefore far more likely to engage in strategic behaviors meant to exploit the shortcomings of a marginal or short-run mixed approach, and reap the benefits of a limited or narrowly construed cost-benefit analysis method. For this kind of defendants, a tailored more expansive review is especially warranted, even at the expense of higher administrative costs, and even if multiple "Hand Formulas" are eventually applied as a result.

In order to limit strategic behaviors, this thesis therefore advocates that an increase in the complexity of a system must often be met with a corresponding increase in the depth of negligence inquiry. This, in opposite to conventional wisdom in law and economic literature, which holds that "an increase in the administrative cost of the system... curbs the number of precautionary measures that courts should consider relevant for finding of negligence."<sup>338</sup> A negligence regime that does not meet the challenge of technological complexity with an equally sophisticated adjudication process, even at the expense of high administrative costs, is likely to fall short of creating efficient incentives, and invite value-destroying strategic behavior.

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<sup>338</sup> Dari-Mattiacci, *On the Optimal Scope of Negligence*, *supra* note 22, at p. 351.

## F. NOTE I: ON ACTIVITY LEVEL VARIABLES

To some extent, the choice between mixed approaches and the number of degrees of freedom to be applied is associated with setting the boundary between care measures and “activity level” variables.<sup>339</sup> “The distinction between the concepts of care and activity level is fundamental for the law and economics of tort liability.”<sup>340</sup> It reflects the notion that only certain variables enter into negligence inquiry, while other factors—broadly labeled activity level—do not. To use a previous example, the speed of a car at the time of an accident is usually a major factor in determining negligence, while assorted other factors, such as the average daily travel distance, average speed, frequency at which the rearview mirror is used, route chosen, purpose of the drive and the option to substituting a car for the train, are usually not considered.<sup>341</sup> When that is the case, potential tortfeasors might exploit the limited scope of the negligence standard to take make socially suboptimal (yet personally-advantageous) choices, and “choose socially excessive activity levels.”<sup>342</sup>

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<sup>339</sup> On the artificiality of this distinction see Anderson, *The Missing Theory of Variable Selection*, *supra* note 22, at p. 262-263; Dari-Mattiacci, *On the Optimal Scope of Negligence*, *supra* note 22, at pp. 334-337; and Peter A. Diamond, *Single Activity Accidents*, 3 J. LEGAL STUD. 107, 110 (1974). For the prolific debate on activity levels and in the negligence context see *supra* note 21, in Part I and our discussion of variable selection in Section IV.B.g.

<sup>340</sup> Dari-Mattiacci, *On the Optimal Scope of Negligence*, *supra* note 22, at p. 334.

<sup>341</sup> See Shavell, *Economic Analysis of Accident Law*, *supra* note 12, at pp. 5, 9, 17, 25, 50-57 (“The number of miles an individual drives, for instance, might be interpreted as his level of activity, and the precaution he takes when on the road (slowing for curves, paying attention to the presence of bicyclists) as his level of care. Similarly, how often a bicyclist rides where there is automobile traffic might be regarded as his level of activity, and his precaution when riding (staying close to the side of the road, using a brightly colored vest) as his level of care.”). Several commentators pointed to the long-run inefficiencies associated with ignoring the choice between driving and other means of transportation and the purpose of the drive, see Anderson, *The Missing Theory of Variable Selection*, *supra* note 22, at pp. 270-271; Aaron S. Edlin and Pinar Karaca-Mandic, *The Accident Externality from Driving*, 114 POL. ECON. 931, 932 (2006); and Jerry Green, *On the Optimal Structure of Liability Laws*, 7 BELL J. ECON. 553, 559 (1976).

<sup>342</sup> Steven Shavell, FOUNDATIONS OF ECONOMIC ANALYSIS OF LAW 196 (2004). The general convention in scholarship is indeed that when the level of activity is not taken into account, potential tortfeasors might meet the standard of due care but operate at an inefficient (too high) activity level. For instance, a driver who otherwise takes adequate care-measures might drive more hours or miles than optimal, assuming the frequency of driving will not be taken into account by courts. See Cooter and Ulen, *Law and Economics*, *supra* note 4, at pp. 348-349; Steven Shavell, *Economic Analysis of Accident Law*, *supra* note 12, at p. 66-71; and Landes and Posner, *The Economic Structure of Tort Law*, *supra* note 3, at pp. 66-73.

As discussed in Part IV, any system of negligence must constantly define which factors will be taken into account in its inquiry, and which will not. Variables that enter the inquiry are termed precautions (or care measures), while those who do not are sometimes labeled “activity level”.<sup>343</sup> This distinction is semantic and juristic, rather than ontological or descriptive. As put by Shavell, “what is important about the variable ‘activity level’ is only that it is not included in the care standard,”<sup>344</sup> and “the only crucial divide between care and activity level is the fact that negligence rules incorporate care but do not incorporate activity level.”<sup>345</sup>

Frequency, repetition and intensity claims often do not enter into negligence cost-benefit analysis, as hinted by the term “activity level”, and are believed to implicate high administrative costs. As Miceli notes, the decision “how frequently or intensively to engage in a risky activity” is generally excluded from the negligence criteria.<sup>346</sup> However, empirically

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Interestingly, Gilo and Guttel have demonstrated in a recent article the possibility of an opposite manipulation, *i.e.* suboptimal precautions coupled with suboptimal activity level (assuming both factors are taken into account), while otherwise adhering to the underlying assumptions of the conventional model; See Gilo and Guttel, *Negligence and Insufficient Activity: The Missing Paradigm in Torts*, *supra* note 184 (“Because negligence requires investments in only cost-justified care, parties might deliberately limit their activity so that the size of the ensuing risk would be lower than the cost of welfare-enhancing precautions”); but compare Grady, *Response, Another Theory of Insufficient Activity Levels*, *supra* note 163 (noting the Gilo-Guttel model as “important” while arguing that it reflects corner solutions, contingent on the assumption of nondifferentiable costs and assets in the long-run).

<sup>343</sup> This usage might be somewhat confusing in light of our view of care as an output, but are nonetheless used in this sense in literature. Recall that generally in this thesis, we view precautions or care measures as variables or inputs of care, precaution levels simply as the level at which of each precaution is taken, care levels as various possible outputs of safety (or isoquant lines of safety), due care as a legal standard denoting the line between liability, and exemption from liability and activity level as a general term for factors that are not taken into account in negligence analysis.

<sup>344</sup> Shavell, *Strict Liability versus Negligence*, *supra* note 21. See also Anderson, *The Missing Theory of Variable Selection*, *supra* note 22, at p. 262.

<sup>345</sup> Shavell, *Economic Analysis of Accident Law*, *supra* note 12, at pp. 9-46. For a somewhat critical view, attributing immutable and realistic (rather than semantic) meanings to the term activity level, see John J. Donohue, *The Law and Economics of Tort Law: The Profound Revolution (Book Review of William M. Landes and Richard A. Posner, The Economic Structure of Tort Law and of Steven Shavell, Economic Analysis of Accident Law)*, 102 HARV. L. REV. 1047, 1062 (1989); Howard Lantin, *Activity Levels, Due Care, and Selective Realism in Economic Analysis of Tort Law*, 39 RUTGERS L. REV., 487, 503 (1986); Louis Kaplow and Steven Shavell, *Economic Analysis of Law*, HANDBOOK OF PUBLIC ECONOMICS (Alan J. Hawerback and Martin S. Feldstein eds., Amsterdam); and Gilles, *Rule-based Negligence and the Regulation of Activity Levels*, *supra* note 21, at pp. 319, 329.

<sup>346</sup> Thomas J. Miceli, *The Economic Approach To Law*, *supra* note 91. For a similar definition, see Cooter and Ulen, *Law and Economics*, *supra* note 4, at p. 332.

and conceptually, courts consider some frequency claims in negligence analysis, and exclude certain non-frequency claims from it.<sup>347</sup> The idiom “activity level” is therefore both “under-inclusive and over-inclusive.”<sup>348</sup> It should be understood as an artificial simplification, or concretization, of a broader idea—a demarcation between included and excluded variables in negligence analysis—not in a literarily sense.<sup>349</sup>

From an economic perspective, the decision which variables will be considered is thought to entail a straightforward balance between the administrative costs of verifying and considering certain variables on the one hand, and the perceived benefits from regulating the underlying behaviors or the level of those precautions on the other. When administrative costs are high and possible benefits from regulating behavior are low, the related variables should not be taken into account. When administrative costs are low and the possible benefits of regulating behaviors are high, variables ought to be contemplated. Dari-Mattiacci describes the division between care measures and activity level using an allegory to a school of fish:

“[T]he set of precautions may be analogized to a school of fish. When one employs a fishing net (the negligence criterion) some fish will be caught (care) while some will swim away (activity level). [The pertinent issue is] the optimal size of the fishing net (the optimal scope of negligence, which balances the (administrative) costs of having a

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<sup>347</sup> On that see Gilles, *Rule-based Negligence and the Regulation of Activity Levels*, *supra* note 21, at p. 320 (“Modern American negligence law regulates activity levels to a considerably greater scope than has previously been recognized”); Shavell, *Economic Analysis of Accident Law*, *supra* note 12, at p. 26; and Landes and Posner, *The Economic Structure of Tort Law*, *supra* note 3, at pp. 70-71. But see David Rosenberg, *The Judicial Posner on Negligence Versus Strict Liability: Indiana Harbor Belt Railroad Co. v. American Cyanamid Co.*, 120 HARV. L. REV. 1210, 1212 (2007) (“Indeed, courts often shy away from tackling this set of especially complex and elusive issues, thereby allowing actors to engage in excessive levels of risky activity.”). For more on the theoretical need to include frequency claims into negligence analysis see Alan J. Meese, *The Externality of Victim Care*, 68 U. CHI. L. REV. 1201, 1206 (2001).

<sup>348</sup> Dari-Mattiacci, *On the Optimal Scope of Negligence*, *supra* note 22, at p. 336.

<sup>349</sup> The distinction between suitable and unsuitable variables for optimization under the Hand Formula also subject to technological changes. In other words, certain behaviors can move in and out of negligence analysis pursuant to technological changes affecting their verifiability, observability or impact on expected harm. For a related discussion, see Gilles, *Rule-based Negligence and the Regulation of Activity Levels*, *supra* note 21.

bigger net with the benefit of catching more fish (improved incentives to take precaution).”<sup>350</sup>

The distinction between activity level and care measures is not, however, synonymous to degrees of freedom, and the two terms should not be confused. The boundary between activity level and care measures determines the scope of variables that will be taken into account in negligence analysis. Degrees of freedom and mixed approaches, on the other hand, are far broader terms, defining not only *which* variables will be considered, but also *how* negligence inquiry will be performed. They define the temporal and sequential scope considered, the maximum number of variables to be weighted together and the nature of the variables reviewed, and may be tailored to the aims and values sought, the strategic behaviors and biases anticipated and the specific wills of the litigants. Furthermore, the term activity level was conceived against the backdrop of the conventional model and the marginal approach. If anything, it served to *de-facto* obscure the multidimensional nature of most tort puzzles, and allow them to be modeled using a single axis. Our approach works to the contrary—it serves to expand our view of negligence, rather than reducing it.<sup>351</sup>

#### **G. NOTE II: ON OPTIMAL PAST-TAKEN PRECAUTIONS**

In an exceptional commentary, Shavell rightly notes that, in certain settings, “the level of due care used to determine negligence is that which is socially optimal *provided* that parties have taken optimal prior precautions.”<sup>352</sup> In other words, courts sometimes “hold parties to the

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<sup>350</sup> Meaning an economic test for which variables and claims should and should not be taken into account. See Dari-Mattiacci, *On the Optimal Scope of Negligence*, *supra* note 22, at p. 333 (otherwise abiding by the traditional economic assumptions of the conventional model).

<sup>351</sup> Interestingly, some “frequency claims” or classic activity level variables are likely not to interact with other precautions, providing a further possible reason for their exclusion from negligence analysis in appropriate cases.

<sup>352</sup> Shavell, *Economic Analysis of Accident Law*, *supra* note 12, at pp. 78, 91-93 (discussing acquisition of

level of due care that would be required if their prior behavior had been appropriate.”<sup>353</sup> In those cases, negligence inquiry seems to take past alternatives into account, and does not consider all preexisting settings as constraints.

For example, as argued by Shavell, courts hold drunk drivers “to the level of care that would be required of a sober individual,”<sup>354</sup> and assume that drivers have “taken the prior precaution of keeping [their] brakes in good repair.”<sup>355</sup> By that, courts hold drivers to a level of care that requires a combination of a past precaution (avoiding intoxication and maintaining adequate brakes) and a present one, and assume at the marginal moment that optimal past precautions have been taken. Courts may also assume, for the purpose of setting the required level of care, that “parties have made reasonable efforts to apprise themselves of risk” in the past.<sup>356</sup> Here also, courts set the level of care assuming injurers have taken certain (“optimal”) prior precautions.

Shavell’s point on past optimal precautions is important, and uniquely touches upon the challenges of negligence adjudication against the backdrop of interacting, multidimensional and sequential precautions. More specifically, Shavell seems to make two distinct arguments: (i) descriptive, according to which courts actually assume that past optimal precautions have been taken when applying the negligence standard, at least in some cases;<sup>357</sup> and (ii) normative,

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information and voluntary intoxication; emphasis in the original).

<sup>353</sup> Shavell, *ibid.*, at p. 79.

<sup>354</sup> *Ibid.* See also Susan Rose-Ackerman, *supra* note 199, at p. 91.

<sup>355</sup> Shavell, *ibid.*

<sup>356</sup> *Ibid.*

<sup>357</sup> I agree with Shavell that, in some cases, court do not adhere to the marginal approach. However, that is a descriptive point, which is not examined in the thesis, and is closely linked to the broader question of whether, and to what extent, courts apply economic reasoning and the Hand Formula in deciding cases. If anything, the fact that court to not rigorously apply the marginal approach serves to show it limitations, and in that sense supports the general claims made here.

according to which assuming past optimal precautions have been taken is a good policy, and will induce efficient incentives on prospective tortfeasors. On this normative point, Shavell's account merits further review.

To the extent that courts actually verify "whether a party took due care"<sup>358</sup> in the abstract, assuming hypothetical and unmaterialized conditions have been met, they do not apply the marginal approach. If this account were actuate to all cases, it would mean that courts essentially attempt to conclusively determine what combination of precautions is required for any particular setting, and measure the defendant's behavior against that standard of care. In other words, Shavell points to the aggregated approach as a possible solution applied by court to the problem of long-run efficient incentives in settings characterized by multidimensional and interacting precautions, but ignores the many limitations of the aggregated approach. He also disregards in that sense the general convention in legal scholarship that the marginal approach is normatively and descriptively accurate.<sup>359</sup>

Consistently conducting a negligence inquiry under a judicial fiction that past optimal precautions have been taken, as advocated by Shavell, would entail considerable practical and normative difficulties. For instance, finding the socially optimal precautions for the present, assuming optimal prior precautions have been taken in the past, would be exceedingly expensive, and is *de-facto* equivalent to setting the optimal level of due care ( $x^*$ ) in the abstract. It would require not only an inquiry into the costs and benefits of all possible precautions, but also an in-depth analysis of all possible contingencies, past decision points and unaccounted interactions. If applied, it would compel adjudicators to construct an imaginary

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<sup>358</sup> Shavell, *Economic Analysis of Accident Law*, *supra* note 12, at p. 78.

<sup>359</sup> See above, in Section I.F. (discussing the golden standard of negligence law).

world consisting of the hypothetical precautions the defendant should have taken (or the different levels of precautions that could have been taken), and envision the effects of these hypothetical precautions on the choices the defendant faced between that time and the time of the accident. It will also require an extraordinarily complex review of factual and legal causation. Finally, it would require litigants to incur the costs of examining all possible combinations of precautions, and plead their case with the appropriate level of detail and complexity. Even in the simplest of settings, therefore, applying Shavell's suggestion would not be an easy feat.

Furthermore, and importantly, Shavell does not specify when should untaken optimal past precautions be viewed as if they were taken, and when should existing conditions be considered constraints. Apart from anecdotally pointing to such examples as intoxication and acquisition of information pertaining to future risks, Shavell therefore does not provide a general theory that helps solve the normative dilemmas associated with interacting sequential precautions. His commentary does not provide guidelines for variable selection, does not reconcile the innate tension between short-run and long-run optimization and does not help ameliorates the costs associated with applying an aggregated analysis.<sup>360</sup> All in all, the claim

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<sup>360</sup> Additionally, any attempt to conduct a negligence inquiry under the assumption that optimal past precautions have been taken will have to answer a supplementary critical question—"optimal at what time"? Cost and efficiency functions can change over time, so that an action might be optimal when taken yet suboptimal or even detrimental at later times. Similarly, it is possible for an action to be inefficient or suboptimal in the past, yet enter the optimal set later on. These types of changes might render attempts to adjudicate the present while presuming optimal past precautions have been taken increasingly difficult.

If the efficiency of past hypothetical actions is examined from the perspective of the past, problematic results might sometimes be reached from the standpoint of the present. For example, if the defendant has taken an inefficient action in the past, and that action later entered into the optimal set (*i.e.* became efficient assuming the conditions of the present), a court might find the defendant acted negligently for taking an action that later turned out to be efficient. Similarly, if two defendants take the same precautions at different times, and a temporal change in costs and efficiency functions occurred in the interim, a court might find one defendant liable while holding that the other acted reasonably, even though the two defendants ended up taking the same precautions.

If, on the other hand, the efficiency of past hypothetical actions is examined from the perspective of the present,



that prior precautions are sometimes taken into account remains highly fact specific, and does not capture the full breadth and width of complexity associated with applying mixed approaches.

If a general conclusion can be extracted from the examples brought by Shavell, it is that a comprehensive review of untaken past optimal precautions is appropriate only in unique circumstances, where conditions exist to limit the costs of judicial review. Such conditions are more likely when, for instance, (i) the timespan between actions is short, *i.e.* the sequential actions or omissions are close in time; (ii) a later precaution is contingent upon a past precaution, rather than simply affected by or correlated with it; (iii) the past precaution is strictly beneficial in terms of reducing accident costs, and the uncertainties associated with it are limited; (iv) the beneficial effect of the prior precaution is easily observable and verifiable; and (v) no changes in costs and efficiency functions of the relevant precautions occur during the relevant timespan.

Not surprisingly, these conditions are met in Shavell's examples. For instance, intoxication lasts for only a short time period, and is close in time to the accident, has a tremendous impact on the defendant's capacity to drive with care, avoiding intoxication is always beneficial from a safety perspective, and its advantages can easily be asserted. When these conditions are not met, however, at least in part, applying Shavell's scheme would require courts to venture far astray from actual events, and conjure evermore-complicated hypothetical scenarios. For each hypothetical assumption regarding an untaken optimal past behavior, the court might be bound to imagine subsequent hypothetical actions that should have followed.

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*i.e.* based on hindsight evaluation, problematic and even illogical results might follow. For example, a court might be required to find a defendant liable for taking an action that seemed reasonable at the time, and was later found to be inefficient. Similarly, a court might find a defendant not liable for taking an unreasonable action in the past, when that action later turned out to be efficient or optimal.

Examined through this lens, the prevailing tendency of negligence law to limit the number of variables or degrees of freedom considered, and the scope of the analysis allowed, has merits, as we have already discussed.

## PART VI: CONCLUSION

### A. TWO LESSONS FROM ANCIENT GREECE: TRAGEDY, HEROES AND THE HEAVENS

#### a. WE NEED A HERO! (OR DO WE?)

In the classic Greek tragedy, the plot would sometimes thicken to a point of such convolution, that no organic resolution of the conflict seemed plausible. An intricate web of wants, needs, wills, past actions, future hopes, moral imperatives and legal duties was weaved together into an entanglement that baffled even the most ingenious of Greek tragedians. Unable to steer the storyline away from total imbroglio, the ancient tragedians would resort to miracles—heroes, “racing on a thunder and rising with the heat”<sup>361</sup> to save the day.

The unanticipated hero or divine deity would appear from the heavens, lowered to center stage using a crane or lift, and proceed to craft a wondrous ending to the seemingly hopeless tale.<sup>362</sup> This literarily ploy was hence termed *dues ex machina*—“god from the machine”—and became synonymous with a contrived and unexpected form of intervention, providing artificial resolutions to seemingly insoluble crises. *Deus ex machina* solutions were detached from the general storyline, and held frail connection to its narrative and events. Such solutions provided an ending *ex-nihilo*—“out of the blue”—indifferent to past occurrences, undaunted by future concerns and pervious only to the last scene. This lack of coherence earned *deus ex-machina* great criticism, for good reason.

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<sup>361</sup> Bonnie Tyler,  *Holding Out for a Hero*, on SECRET DREAMS OF FORBIDDEN FIRE (CBS 1986).

<sup>362</sup> This ploy was especially common in plays by Sophocles and Euripides.

Millennia have come to pass, and highly intricate plots are now as common in modern life as they were in Greek theater. With human knowledge continuing to expand exponentially, doubling its breadth at unimaginable rates, and our social systems more intricate than any point in history—simple explanations have become rare. As laymen meanings fall out of favor, the same impetus that drove the Greeks to seek their *dei ex machina*—a yearning for simple resolutions and understanding—now sends us in search of new heroes. Once more, we seek heroes to provide coherent meanings and clear-cut answers.

In negligence law, the hero has a name—the marginal approach. Yet, it is by no means a mighty dashing Apollo. Memoryless, shortsighted, impatient, predictable, awkward and crippled by criticism—the marginal approach is more a postmodern anti-hero than “a white knight upon a fiery steed.” It holds on to all of the flaws of the classic *deus ex-machina*, but does not profess to his imperfections and limitations. While its ancient predecessor was never thought to be anything but an actor in a shiny suit, the marginal approach hides the crane from which it hangs high above, and the underlying assumptions from which it stems.

The irony in our current search for legal heroes is that tort law in the 21<sup>st</sup> century does not need white paladins and herculean champions, with easy solutions and miracle scales. What it needs are people with foresight, imagination, prudence, critical thinking and careful discretion. Where heroes offered strength and resolve, we need sophistications and in-depth reflection. Where heroes offered immutable laws and unassailable truths, we need curiosity, insight and flexibility. Where heroes offered brute force, maxims and angry determination, we need wit, empirical profoundness and clarity of mind. Where heroes once offered fixed solutions, we now need tailored approaches.

## b. A VIEW OF THE HEAVENS

The Ancient Greeks can provide us with an additional lesson from the past, in the form of the dangers associated with crafting a general model based on theoretical simplifications and lofty philosophical maxims. This lesson originates from arguably the most renowned example of a paradigmatic shift<sup>363</sup> and revolutionary science—the turn from the Aristotelian and Ptolemaic cosmology<sup>364</sup> to the heliocentric worldview.

Predicated upon the axioms that the earth is stationary at the center of the universe, and that the heavens move in perfect circular paths, the Aristotelian view of the heavens established one of the most elaborate, complicated and fascinating models of the cosmos.<sup>365</sup> Exerting unparalleled influence over ancient and medieval astronomy, it was a model of true beauty and elegance. This view was also, as is by now commonly accepted, fundamentally flawed.

What is interesting about the story of the Aristotelian cosmology for our purposes here is not so much the process by which scientific paradigms shift (which has been the subject of considerable debate in philosophy of science), but rather its emergence, logic and preservation. The Aristotelian model was a system built upon a series of simple and unyielding assumptions, fashioned for their grace and purity, derived from philosophical conjecture, and generally devoid of an empirical substantiation processes. Confined by the truism that the supralunar region is one of eternally unchanging cycles, where all movement is uniform,

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<sup>363</sup> For the originating use of these terms, see Thomas S. Kuhn, *THE STRUCTURE OF SCIENTIFIC REVOLUTIONS* (1962). See also Thomas S. Kuhn, *THE COPERNICAN REVOLUTION—PLANETARY ASTRONOMY IN THE DEVELOPMENT OF WESTERN THOUGHT* (1957).

<sup>364</sup> For simplicity, our discussion here does not distinguish between Aristotelian and Ptolemaic theory, or points to the notable refinements and adaptations made to these models going to the 16<sup>th</sup> century.

<sup>365</sup> For a comprehensive historic account see David C. Lindberg, *THE BEGINNINGS OF WESTERN SCIENCE—THE EUROPEAN SCIENTIFIC TRADITION IN PHILOSOPHICAL, RELIGIOUS, AND INSTITUTIONAL CONTEXT, PREHISTORY TO A.D. 1450* 45, 53-61, 86-93 (1992), and the multiple sources listed there.

uncorrectable and immaculate, it commanded that the stars move in flawless continuous circles, and religiously rejected any view to the contrary.<sup>366</sup>

In the negligence context, the conventional model risks an Aristotelian fallacy, and veers dangerously close to paradigmatic misconceptions. Just like the Aristotelian model, the conventional economic theory of negligence is organized around a set of simplified assumptions, prized precisely for their elegance and “cleanness.”<sup>367</sup> Just as the Aristotelian map, the conventional model stems from abstract ideals, rather than adherence to empirical observations. Similar to the ancient view of the heavens, the conventional model of negligence is highly fragile, and while intended as a general theory, it is at best demonstrative of highly specific cases. Indeed, reasoning that the stars impeccably move in ethereal monotonic spheres or that precautions are orthogonal and monotonically convex does not make them so.

## **B. NEGLIGENCE LAW FOR A COMPLEX WORLD**

Negligence law is best conceived as an exercise in solving optimization puzzles. As this dissertation claims, this is one of the most elusive yet helpful ways to truly understand the law of negligence from an economic perspective. Negligence analysis entails a constant effort to disentangle intricate multi-variable scenarios—to find efficient solutions to sometimes immensely complicated functions and settings. Many of the problems facing negligence

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<sup>366</sup> See Aristotle, *On the Heavens*, in THE COMPLETE WORKS OF ARISTOTLE—A REVISED OXFORD TRANSLATION 451 (Jonathan Barnes, ed., 1984), complemented by the short yet influential passage in Aristotle, METAPHYSICS, XII.8 (Richard Hope trans., 1960) (“There is, then, something which is always moved with an unceasing motion, which is motion in a circle; and this is plain not in theory only but in fact. Therefore the first heaven must be eternal. There is therefore also something which moves it. And since that which moves and is moved is intermediate, there is something which moves without being moved, being eternal, substance, and actuality.”).

<sup>367</sup> Recall Cooter and Ulen’s statement, “[i]t is usually best to build theory from clean results and then handle any messy results as exceptions.” (Cooter and Ulen, *Law and Economics*, *supra* note 4, at p. 210).

adjudication and theory today are plainly or tacitly related to the challenges posed by multidimensional and threshold optimization puzzles. Surprisingly enough, these challenges have scarcely been considered by legal scholarship. As a result, our most basic notional approach to negligence is theoretically impaired and practically unfitting.

In the realities of modern technology, the risks and challenges associated with oversimplifying negligence problems warrant special attention. As human endeavors become more advanced and ambitious, adjudicating negligence becomes more difficult. This is especially true for litigation involving high-tech and research-driven industries. Pharmaceutical developments, financial derivatives, software innovations and deepwater drilling, to name a few, can be amazingly complex and involve highly compound dilemmas, far exceeding the intricacy level discussed here.<sup>368</sup> In all these cases, interacting precautions, substitutable options, threshold effects and discontinuous outputs are the prevailing norm, not the exception.

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<sup>368</sup> Financial derivatives are an interesting example of the difficulties of implementing the Hand Formula in a complex-variable environment. Consider the case of residential mortgage backed securities (RMBS), or the type that underlie the 2008 financial crisis. The overall performance of any individual RMBS bond (or tranche of an RMBS bond) is principally contingent upon the value of its supporting loan group (SLG), or the mortgage loans serving as collateral for the cash flow from the securitization (subject to a few structuring mechanisms, such as caps and cross-collateralization). To assess the value of such each loan within the loan-pool collateral, roughly 20 different parameters might be considered relevant and material—for instance, the ratio between the borrower’s debt and her income (DTI), the ratio between the size of the loan and the value of the property (LTV), the borrower’s FICO score, whether the property is owner-occupied, whether there is a second lien on the property in question, the geographical location of the property, the occupancy period, the existence of mortgage insurance, and more.

What is interesting is that the effect of each parameter on the probability of default and on expected loss severity (and of course, the value of the loan), is highly correlated with the other parameters. Thus, for example, a 5% increase in LTV ration might have little to no impact on the probability of default in some settings, but a dramatic impact in others. Also, each parameter often exhibits threshold effects. For instance, a deterioration of FICO score from 700 to 690 might not impact the probability of default at all, whereas a drop from a 650 FICO score to 640 will have a dramatic impact. Similarly, an occupancy period of anywhere between 2 to 30 years can have no impact on the probability of mortgagor default; whereas an occupancy period of under a year would increase the chances of default dramatically. On top of all these, the structure of the securities makes the characteristics of the overall loan pool—not only individual loans—critical. For instance, the distribution of different parameters over different loans greatly affects the value of each tranche or bond, so that two loan pools might have identical average collateral characteristics, yet very different values. Under such conditions, assessing issuers’ conduct and diligence according to a quasi-negligence standard, as required in various defenses under securities laws, creates substantial difficulties, and illustrates the innate limitations of the marginal approach. See, for instance, James R. Barth, *THE RISE AND FALL OF THE U.S. MORTGAGE AND CREDIT MARKETS* (2009); Michael Lewis, *THE BIG SHORT* (2010); and Bethany McLean and Joe Nocera, *ALL THE DEVILS ARE HERE—THE HIDDEN HISTORY OF THE FINANCIAL CRISIS* (2010).

Modern technology therefore exacerbates the normative and practical difficulties posed here, and reinforces the need to take a deeper look at the current cost-benefit analysis schemes in tort law. An ever-advancing world of scientific and engineering revolution constantly transforms previously regarded reasonable actions into negligent behaviors,<sup>369</sup> posing an incredible strain on the negligence system. More importantly, 21<sup>st</sup> century technology creates ever more challenging optimization puzzles, and facilitates new forms of strategic manipulations by prospective tortfeasors. Viewed from this perspective, the need to rethink our theoretical conception of negligence and craft “a new paradigm of tort liability”<sup>370</sup> cannot be overstated.

The discussion throughout this thesis should cast a somber shadow on the applicability and viability of the marginal approach as the golden standard of negligence, and foster doubt as to its sufficiency as a *sine qua non* adjudication method. At the very least, the difficulties posed here should lead to considerable skepticism as to the aptness of current economic theory to achieve efficient outcomes, and encourage the development of new rubrics for negligence adjudication. The same skepticism should be afforded to schemes outside of tort law that are inspired by the Hand Formula, such as in of corporate, contract, criminal and constitutional law.

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<sup>369</sup> Grady made a similar claim, stating that negligence is fundamentally a “creature of technology”; see Grady, *Why are People Negligent?*, *supra* note 122, at p. 293 (1988); and Grady, *Response, Another Theory of Insufficient Activity Levels*, *supra* note 163, at p. 33 (“This analysis reveals a deep paradox in the civil liability system... basic safety technology often increases the rate and amount of negligent behavior.”).

<sup>370</sup> Grady, *Response, Another Theory of Insufficient Activity Levels*, *supra* note 163, at p. 36.