Essays on the Economic Analysis of Tort Law

Essays over de economische analyse van het onrechtmatigedaadsrecht

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Contents

1. Introduction

One of the most important objectives of tort law is to provide potential injurers and victims appropriate precautionary incentives to avoid an accident when undertaking risky activities.[1] Since the pioneering work of Trimarchi (1959a,b, 1961, 1967), Calabresi (1961), Posner (1972), Brown (1973) and Shavell (1980), tort law scholars have stressed the social goal to minimize accident costs and the deterrent function of liability rules, namely the threats of being held liable and uncompensated injury induce parties in an accident setting to take optimal care. The application of economic concepts to tort has undergone a rapid development in the US and has also clearly expanded to other continents. In the last 40 years, the literature has developed so quickly that an encyclopedia completely devoted to tort has become necessary (Faure, 2009a).[2]

Notwithstanding the exhaustive number of contributions on tort law and economics,

[1] Tort law is frequently said to serve two purposes: the compensation of victims and the deterrence of accident (e.g., Shapiro, 1991). The dominant perspective of the economic analysis of tort law is to evaluate the efficiency of liability rules in terms of the precautions and activity-level incentives that they create. This economic interpretation of tort law is not the only one, although it has undoubtedly become the dominant perspective. See Parisi (2001) for a historical perspective on the development of tort law. See also Posner (1972), Dewees et al. (1996), Kaplow and Shavell (2002, p.151) showing that tort law is a slow and expensive way of providing compensation.

[2] The *Encyclopedia of Law and Economics* was published in 2000 by De Geest and Bouckaert, and builds on the *Bibliography of Law and Economics* (De Geest and Bouckaert, 1992). Both these volumes merely contained literature references to the various domains of law and economics. Faure (2009a) collected topics exclusively related to the economics of tort.

there remain several open questions and different issues that warrant further investigation. The general aim of my research project is to refine the traditional model of tort law in the attempt to make it more realistic, updated with the recent technological progress and in line with the experimental results concerning other-regarding preferences.

This thesis is divided into six chapters: Chapters 1 (this chapter) and 6 provide an introduction and conclusions, respectively, while the remaining chapters are written in the form of separate yet related articles. Different methodologies are used to investigate four main issues that have been understudied in the extant literature: the efficient allocation of residual liability (Chapter 2); the characterization of efficient liability systems in accidents involving automated technologies (Chapter 3); the optimal definition of legal presumptions in a tort setting (Chapter 4); and the actual precautionary behavior of potential injurers and victims (Chapter 5). In the following, I will highlight the research questions and discuss their social and academic relevance, as well as explain the methodology adopted to address each research question.

The first research topic deals with the efficiency of liability rules in terms of activity-level incentives (Chapter 2). The distinction between care level and activity level affects the entire economic analysis of law (see, among others, Dari-Mattiacci and Parisi, 2006 and Parisi, 2013). Polinsky (1980) and Shavell (1980) independently highlighted the relevance of this distinction when the criterion of negligence is used to establish liability, as well as its irrelevance in the regimes of strict liability and no liability. The care level refers to the observable precautions used by courts to ascertain negligence, and indicates the quality of parties' precautionary efforts in carrying out their activities (e.g., vehicle speed, observing road signals). The activity level refers to the other factors that are not taken into account by courts to ascertain negligence and it indicates the quantity (i.e., intensity and duration) of the parties' activities (e.g., how many miles the tortfeasor drove, how often the victim crossed the intersection). The efficiency-equivalence theorem and the activity-level theorem are the two fundamental results in the economic analysis of law based upon the distinction between care and activity levels. The efficiency-equivalence theorem states that under any fault-based liability system, both parties have optimal incentives to comply with the due-care standards, regardless of the loss-sharing rule among negligent parties (Landes and Posner, 1980). Shavell's (1980) activity-level theorem states that none of the standard liability rules can provide both parties efficient incentives with respect to activity levels.

The traditional analysis of accident law primarily focuses on care incentives and on the optimal definition of standards of negligence. Plausibly, the relative lack of scholarly interest in "non-negligent" accidents may be attributable to a sense of resignation that optimal activity levels are unachievable under traditional tort rules, along with concerns about the accessibility of activity-level information. However, under any fault-based liability system, prospective injurers and potential victims have incentives to comply with due-care standards (Landes and Posner, 1980), and some of the accidents that occur in reality arise despite the due diligence of the individuals involved. For this reason, the allocation of the residual liability plays a crucial role in minimizing expected accident losses and it warrants more attention.

It is commonly ascertained that only the residual bearer (i.e., the party that bears accident costs in equilibrium) has incentives to reduce his or her activity level (Shavell, 1980). Residual liability is traditionally allocated either entirely on the tortfeasor (strict-liability-based rules) or entirely on the victim (negligence-based rules). Dari-Mattiacci and Parisi (2013) and Dari-Mattiacci et al. (2014) provide an exhaustive overview of the allocation of the residual liability under the traditional liability systems. The effect of this all-or-nothing allocation is that one party (the bearer of residual liability) is fully incentivized to undertake an optimal level of activity, while the other (the non-bearer of residual liability) has no legal incentives to mitigate his or her activity level. Recent contributions have discussed the possibility of sharing the residual loss, showing that loss-sharing rules do not undermine parties' compliance with due-care standards. More specifically, Parisi and Fon (2004) studied the efficiency of comparative causation, under which the residual loss is shared among parties based upon their causal contribution to the accident. Parisi and Fon showed that parties' incentives to undertake due-care levels are preserved even when the residual loss is shared, while the incentives to exert excessive activity levels are mitigated for both parties. Parisi and Singh (2010) revisited this issue, highlighting the virtues and desirable properties of the rule of comparative causation, providing further proof that loss-sharing rules are efficient in creating optimal care incentives. In their final remarks, Parisi and Singh (2010) raised the question about the conditions under which the rule of comparative causation should be preferred to alternative liability rules in real-life contexts. This can be seen as a specific version of the research question posed in Chapter 2 of this work. In fact, having acknowledged that loss-sharing rules might be a valuable alternative to traditional all-or-nothing based rules since parties' compliance with due-care levels is not undermined, the question that emerges is *when* loss-sharing should be employed in place of all-or-nothing rules and vice-versa. Particularly relevant to Chapter 2 is the most recent contribution on this topic by Dari-Mattiacci et al. (2014), who studied a generic fault-based liability rule in which the accident loss is shared among negligent parties and non-negligent parties. They generalized the compatibility of loss-sharing rules with optimal care incentives and provided examples on the optimal loss-sharing rule among non-negligent parties when parties' activities are independent of each other in the production of the expected accident loss.

The choice between all-or-nothing based rules and loss-sharing rules as alternative allocation of the residual liability has always been taken as given and has only recently been slightly challenged (Parisi and Fon, 2004; Singh, 2006; Parisi and Singh, 2010; Dari-Mattiacci et al., 2014). For this reason, the question about which party should bear the accident costs if care incentives work (i.e., both parties adopt the due level of care) happens to be a crucial question. Therefore, this study first aims to answer the following research question:

1. Under what conditions are traditional all-or-nothing based rules more desirable than loss-sharing rules in terms of activity-level incentives?

In order to influence activity-level incentives, it becomes fundamental to first analyze the characteristics of parties' activities (e.g., riskiness, value) and subsequently study the optimal allocation of the residual loss. The key insight of Chapter 2 is that the allocation of the residual liability should not be treated as given. Traditional economic models of accident law allocate the residual loss on either one party or the other, without accounting for the relevant characteristics of parties' activities. In other words, tort scholars have conventionally treated the residual liability as an exogenous variable in their models. The analysis in Chapter 2 adds to the literature by considering the allocation of residual liability as an endogenous variable, which should optimally depend on the relevant characteristics of parties' activities.

Chapter 2 considers six factors embedded in the cheapest-cost-avoider principle (Calabresi, 1970). Specifically, through a more generalized accident model, Chapter 2 explores all possible relationships between the riskiness and the value of activities, the interaction of the parties' activities in the production of risk, returns to scale from the activities, and parties' relative risk preferences. These factors – which have been almost entirely overlooked in the current literature, with the exception of Nell and Richter (1996) on parties' risk preferences and Dari-Mattiacci et al. (2014) on the riskiness of parties' activities – should optimally guide the allocation of liability costs among faultless parties. The analysis of these factors allows identifying the optimal allocation of residual liability.

Regarding the methodology, this chapter extends the theoretical frameworks used by Singh (2006), Parisi and Singh (2010) and Dari-Mattiacci et al. (2014) following two steps. First, it is proven that under a general fault-based liability system, parties have incentives to comply with the (second-best) due-care standards. Second, the socially optimal allocation of the residual loss is analyzed as depending upon the relevant characteristics of parties' activities. The optimization problem is formulated as a two-stage model where parties' activity and care choices in the second stage are affected by the initial-stage definitions of the due-care levels and the sharing rule between non-negligent parties by the social planner. This essentially means that the social planner designs the optimal liability scheme by anticipating the parties' reactions to marginal increases in liability share.

The results show that loss-sharing rules are more desirable than conventional all-or-nothing based rules in a large range of conditions, such as in the presence of homogeneous risk avoiders (e.g., parties whose activities have the same degree of riskiness, parties with similar attitudes towards risk) and countervailing policy objectives (e.g., a party's activity is riskier yet more valuable than that of the other party).

Residual liability is not only relevant with respect to activity-level incentives, but also for investments in new precaution technologies. My second research question focuses on a specific type of safety technology, i.e., automated technology, such as driverless cars and automated drones. Chapter 3 analyzes the impact of such automated technologies on the law of torts.

Modern automated technologies replace human actions and autonomously perform activities in a broad range of potentially harmful situations, such as driving vehicles, delivering packs, performing surgery operations, unloading trucks and stock merchandise. In doing so, automated technologies remove risk and errors from individuals and place them on autonomous machines. This reduces the probability of negligent harm (e.g., excessive speed, inattention or intoxication causing a road crash), as well as the probability of "unavoidable accidents" (Grady, 2009), i.e., expected harm that the actor could not have foreseen or prevented by exercising reasonable precautions (e.g., a driver losing the control of the car due to health problems, obstacles running out in front of a car and the driver having insufficient time to avoid it).[3] At the same time, this welfare-enhancing shift of tasks from product-users to automated devices raises the question of how to apportion liability among manufacturers, product users and third parties: should negligence law change to encourage the development and adoption of safer automated technologies?

Consider as an example the case for driverless cars. Google and major car manufacturers have developed vehicle prototypes capable of driving, parking and navigating without direct human input (Greene, 2011). This evolution of the automotive know-how offers the potential to change the concept and the network of transportation, promising invaluable social benefits such as saving lives by reducing the number of road crashes,[4] reducing liability claims and insurance costs, lowering fuel consumptions and pollution,[5] assisting people who cannot safely drive, and, ultimately increasing productivity in daily commuting. This technology is almost ready but despite its beneficial impact, only a few U.S. states have authorized the operation of these vehi-

[3] See the definition of "unavoidable accident" in Restatement (Second) Torts (St. Paul, Minn.: American Law Institute, 1965), §8, 8 A, 435 (1965): "The words 'unavoidable accident' are used throughout the Restatement of this Subject to denote the fact that the harm which is so described is not caused by any tortious act of the one whose conduct is in question.". See also Grady (2009): "In negligence law, 'unavoidable accident' is the risk that remains when an actor has used due care. The counterpart of unavoidable accident is 'negligent harm'.".

[4] By replacing human actions with autonomous technologies, it is estimated that nearly 1,9 million of accidents could be prevented, and 9,600 lives could be saved each year if 50 percent of vehicles in the U.S. were self-driving (Fagnant and Kockelman, 2013).

[5] Considering again the estimates by the Eno Center for Transportation, economic annual savings could reach $102 billion ($211 billion, comprehensive) with a 50 percent autonomous vehicles market penetration rate.

cles for testing purposes to date. Beyond technological concerns, the real challenge of self-driving cars lies in unanswered liability questions (Marchant and Lindor, 2012). One of the most debated is: who is liable for accident involving driverless cars? If being distracted, sleepy or intoxicated does not constitute negligent behavior, should the driver still be directly liable for accidents happening without his direct contribution?

The answer to these questions depends upon two objectives of the tort system, namely incentivizing both the production and adoption of new safety technologies. The economic literature on liability law regarding innovative automated technologies remains at an embryonic stage. The conventional economic conception of tort law has indeed assumed the existence of two human actors — a tortfeasor and a victim — although this assumption becomes tenuous with the advancement of automated technologies. My second contribution stands as the first attempt to introduce automation in the traditional model of accident law to evaluate whether and how the current negligence-based liability system should evolve to encourage the creation of a market for new automated technologies. Accordingly, my second research question is the following:

2. Is the current fault-based liability system still adaptable to robotic torts?

Even if errors may occur at substantially lower rates with robots as compared with humans, accidents will nevertheless occur. Legal systems thus have to define the extent to which individuals should be held liable for what an artificial system "decides" to do. This is one of the most innovative aspects in the field of the laws of tort. Chapter 3 addresses this issue and uses a unilateral-care model with automated activity to determine whether and how negligence law should "evolve" to deal with injuries caused by automated technology.

Although the economic literature addresses the elements of automated technology torts, such as durable precautions and compliance-saving technology (e.g., Grady, 2009), and the legal literature addresses certain specialized questions about the tort implications of automated technologies (e.g., Garza, 2011), no one has yet introduced a general theoretical approach to robot torts. Chapter 3 employs a unilateral-care tort model (i.e., the accident rates only depend upon the behavior of the tortfeasor) to analyze the social cost of accidents in cases where the actor is not a human being, but rather an automated technology. This chapter builds upon Shavell's (1980; 1987) unilateral accident model to incorporate the level of activity automation adopted by potential injurers. Automated technologies are modeled by using two assumptions: first, advances in automation reduce the effectiveness of the end-user's precautions; and second, human precautionary care and automated technology safety are substitutes. Accordingly, the probability of an accident occurring decreases as the level of activity automation or the level of care increase. It follows that an increase in automation leads the probability of an accident to decrease. In the limiting case when no investment is made in automation, our model simply reduces to the standard model.

The main result of Chapter 3 shows the desirability of a negligence standard tailored to activity automation. More specifically, the standard of due-care should be optimally tailored to activity automation and should decrease as investments in automation increase. This would create more incentives to adopt safer automated technologies rather than averaged care standards. The decision to also tailor negligence standards to automated-activity levels should depend upon the trade-off between two policy objectives, namely incentivizing the adoption of automated technologies *versus* controlling excessive automated-activity levels, whereby a negligence standard tailored to the automated-activity level creates optimal incentives for automated-activity levels but dilutes the incentives to adopt and use automated devices.

It is worth noting that tort law usually work in tandem with regulation. Indeed, tort law and regulation are two alternative and, in practice, complementary approaches of achieving safety (Calabresi, 1970). Regulation contributes to safety through an *ex ante* mechanism, whereas the tort system through an *ex post* mechanism. Under the liability system of corrective justice, wrongdoers are required to compensate victims for injuries caused by a wrong, with the main goal of generating precautionary incentive streams and inducing parties to internalize the costs of wrongdoing; whereas the regulatory system imposes sanctions for violations. The relationship between tort law and regulation is highly debated (see, among others, Shavell, 1984). Product liability and medical malpractice are considered as the most difficult areas of tort law (see, among other, Faure, 2000, discussing whether product liability and product safety in Europe should be regulated in a decentralised or centralised manner). In these cases parties are not strangers between each others as in classic tort situations, but they are in a preaccident relationship as sellers and buyers or doctor and patient. Some critics pointed out the advantages of *ex ante* regulations in these areas where technical information about health and products are relevant to harm and courts lack of expertise and technical staff to deal with such issues (Viscusi, 1984). In these cases, the tort system can become extremely expensive because of high transactions and administrative costs including legal fees. These costs can be much greater than either private insurance or regulatory cost, and could make the tort system not an efficient system for compensation of victims. In practice, however, torts and regulations are complementary and their joint use is generally socially desirable (Shavell, 1984). For example, tort law can work in tandem statutory regulation when regulatory standards are designed to establish a baseline which a more precise tort doctrine can supplement or when tort doctrines apply absent a more stringent regulatory statute. These arguments certainly hold for automated technologies; for example, the user of a driverless car deciding to manipulate the car speed limit must consider the possibility of liability in case of an accident for wrongful manipulation of the automated technology as well as a speeding ticket. The main focus of Chapter 3 is upon tort law and negligence-based liability systems. My framework can be further extended to consider the desirability of the joint use between tort law and regulation in the presence of automated activities. Indeed, the application of due-care standards tailored to activity automation might lead to high administrative costs and might make regulation preferable to tort law.

Beyond liability and regulation systems, automated technologies could potentially affect the law of evidence. Indeed, the more that these machines become interactive and autonomous, the more that third parties will find it difficult to prove that the manufacturer or the product-user did not conform to a certain standard of conduct. In these cases, questioning the traditional allocation of the burden of proof upon the plaintiffs appears to hold crucial importance. My third research question proceeds along this path by questioning the conventional definition of legal presumptions in a tort setting.

Chapter 4 explores the incentive effects of legal presumptions on a tort setting, which is an important dimension that should inform the allocation of the burden of producing evidence in a contested issue. The core questions of Chapter 4 are as follows: how should the burden of proof be allocated among parties to foster the adoption of evidence technologies? How should the burden of proof be allocated in the presence of discovery errors to preserve parties' care incentives? How should the burden of proof be allocated to mitigate excessive activity levels?

Legal presumptions can be either "*pro plaintiff*" in the sense that the defendant has to prove his diligence (the burden of producing evidence is on the defendant, thereby creating a presumption of negligence on the defendant) or "*pro defendant*," in the sense that the plaintiff has to prove the defendant's negligence (the burden of producing evidence is on the plaintiff, thereby creating a presumption of non-negligence on the defendant). The law of evidence generally places the burden of producing evidence on plaintiffs, *de facto* creating a presumption of non-negligence in favor of the defendant (Talley, 2013). In the event of a negligent accident, this means that a victim is generally faced with the burden of producing evidence about the negligent behavior of his tortfeasor, as a condition for establishing liability and obtaining compensation even if the content of the required evidence relates to the activity of the defendant (Sanchirico, 2008). Previous contributions on the burden of proof (with the exception of Sanchirico, 2008) explained the choice of presumptions based upon parties' relative cost of discovery (Hay, 1997; Hay and Spier, 1997; Shin, 1998), truth-finding by the court (Sanchirico, 2004), and litigation incentives (Sanchirico, 2008). The question arising here is why evidence law generally shift the burden of proof onto the plaintiff (presumption of non-negligence on the defendant) rather than the defendant (presumption of negligence on the defendant), even when the required evidence relates to the activity of the defendant.

The analysis in Chapter 4 adds to this literature by focusing on the effect of evidence rules on tort incentives, which is an overlooked dimension that should inform the choice of legal presumptions. The aim of Chapter 4 follows in a straightforward manner, namely to investigate the optimal allocation of the burden of proof between the plaintiff and the defendant based upon parties' access to the relevant information and the probability of discovery errors. The analytical move of this analysis lies in the interrelated roles that legal presumptions play in a tort setting, whereby the allocation of the burden of proof affects the adoption of evidence technologies, the parties' incentives with respect to care levels, and the parties' incentives with respect to activity levels. The third question of my research project is thus threefold:

3. How does the availability of new evidentiary technology affect the optimal definition of legal presumptions? How should legal presumptions be defined to preserve parties' care incentives in the presence of evidentiary problems? How should legal presumptions be defined to create optimal incentives with respect to activity levels?

Chapter 4 proceeds stepwise by analyzing these three factors. The analysis shows that the conventional allocation of the burden of proof onto the plaintiff could be not efficient in three situations: when the defendant can more effectively invest in evidence technology; when the plaintiff has a high probability of making discovery errors; and when the plaintiff is already burdened by the residual liability.

Regarding the first situation, it is worth stressing that the incentives to adopt private fact-keeping technologies, i.e., technologies privately adopted by individuals to collect information about present events and preserve it for future investigations, are endogenously determined by evidence law. Under existing presumption rules, this could reduce or, in some cases, entirely undermine the parties' incentives to adopt such technology. Indeed, if the information gathered by private fact-keeping technologies (e.g., Snapshot technology) could be used in court against the driver in the event of an accident, the likelihood that any driver might want to adopt such technology would obviously diminish. In terms of the second situation, a shift of the burden of proof between the defendant and the plaintiff affects the parties' care-level incentives when adjudication errors are present. This refines and extends the analysis by Hay and Spier (1997), which argued that the choice between two alternative legal presumptions in a hypothetical world of error-free adjudication would leave care incentives unchanged. To illustrate the point, consider the rule of simple negligence. Suppose that the plaintiff is likely to fail to prove the tortfeasor's negligence and consequently the tortfeasor is likely to avoid liability notwithstanding his negligence. In this case, evidence problems may dilute a tortfeasor's care incentives. The defendant will only undertake optimal care if the probability that the plaintiff will be able to prove the defendant's negligence is sufficiently high. However, as probatory difficulties for the plaintiff increase, a simple negligence rule gradually degenerates into a no liability rule, thus undermining the prospective defendant's care incentives. A change in the legal presumption could mitigate this problem. If a presumption of negligence on the tortfeasor applies, the tortfeasor may fail to produce evidence of his own diligence and thus he may bear full liability notwithstanding his diligence. At the limit, when the proof of non-negligence is excessively costly, the simple negligence rule would degenerate into the strict liability rule, preserving primary care level incentives. Chapter 4 shows that a similar analysis applies to other negligence-based liability regimes, such as the regime of strict liability with contributory negligence. The third role of legal presumptions in a tort setting is related to activity-level incentives, which are not only influenced by the allocation of the residual liability but also by the allocation of the burden of proof. Indeed, a shift of legal presumptions between parties can either depress the activity levels of the residual bearer below the social optimum, or mitigate the excessive activity levels of the non-residual bearer. In a negligence regime, a presumption of negligence would thus be desirable, since it shifts the burden of proof onto the party who is not already burdened by the residual liability, thereby inducing both parties to mitigate excessive activity levels.

Evidence technologies and incentives on care and activity levels are factors that have been overlooked in the traditional literature on evidence law, despite being crucial for the optimal allocation of the burden of proof in a tort setting. The analysis in Chapter 4 reflects the first attempt to highlight these additional factors, and further extensions are possible to better answer the question "which party should produce evidence on a contested issue?". Chapters 4 and 6 discuss future investigations on this topic (e.g., what is the optimal allocation of the burden of proof in a tort setting when all the three factors identified in Chapter 4 point in different directions?).

A final note on Chapter 4 concerns the methodology. The theoretical framework used in Chapter 4 follows Shavell (1980) and Hay and Spier (1997) in studying the optimal allocation of the burden of proof when discovery errors are considered. Chapter 4 uses a simple unilateral-care framework to analyze whether a change in the legal presumption could preserve parties' care incentives in the presence of large discovery errors. This theoretical setup is also used to study parties' incentives to invest in private fact-keeping technologies under alternative allocation of the burden of proof. The analytical move here is to assume that the probability of discovery error is close to zero when the party with the burden of providing evidence adopts evidentiary technologies. The impact of alternative definitions of legal presumption on activity-level incentives is discussed without deriving a formal proof. The logic underlying our discussion is very simple and intuitive. The cost associated with the burden of proof is similar to a tax imposed on the activity levels. The burden of proof can thus be used as an activity level tax with a legal presumption in favor of the residual bearer of the loss.

All the preceding chapters have considered prospective tortfeasors and their victims as risk-neutral individuals, free from any type of prosocial behavioral bias and moral sentiment. However, the literature on prosocial preferences and emphatic behavior shows that people care about others' well-being and feel empathy for others' pain (Cooper and Kagel, 2009; Crockett et al., 2014). The fourth discussion in my dissertation evaluates the role of other-regarding preferences in accident prevention. Imagine that you may either cause material damage to another car, or suffer damage to your car. How many precautions would you like to undertake to prevent damage to another car? How many precautions would you like to undertake to prevent damage to your own car? How would your precautionary decisions change in case of perfect compensation of damages? Are you more averse to being victims of an accident or tortfeasors?

My fourth research question follows in a straightforward manner:

4. Do individuals adopt a different precautionary behavior depending upon their role in an accident?

The conventional analysis of accident law predicts that individuals attribute the same weight to two different actions under mirrored liability rules (i.e., no liability and strict liability), namely causing damage to a stranger and suffering damage. This implies that individuals are expected to undertake the same precautionary choices regardless of their being victims or tortfeasors in an accident context. Under the traditional theoretical framework, liability incentives are role-independent. Chapter 5 questions this theoretical prediction: are liability incentives actually role-independent? Conversely, do people undertake different precautionary behaviors depending upon them being victims or injurers? And, how does feeling responsible for someone else's losses affect precautionary behavior?

This question comes from the growing literature in psychology, neuroscience, behavioral and experimental economics that has investigated other-regarding preferences from different perspectives. Among others, Eckel and Grossman (1996), Fehr and Fischbacher (2004), Fehr and Schmidt (2006), Henrich et al. (2010), Engel (2011) and Rand et al. (2012) have showed that individuals care about the well-being of others and that the evaluation of others' well-being is highly context-dependent. Determining the precise conditions of pro- or anti-social behavior remains under investigation and has several implications for legal and political decision-making.

The main contribution of the research project presented in Chapter 5 is twofold. First, it suggests a novel, non-neutral context (i.e., a car accident situation) to study prosocial behavior, which is substantially different from the standard neutral-context games, i.e., ultimatum and dictator games, used to test other-regarding preferences and altruistic behavior in economic exchanges. The behavioral implications of this research are crucial in understanding how people evaluate others' well-being compared to their own in a context that is closer to daily-life activities. Second, this research adds behavioral insights to the economic analysis of tort law. The result shows that in an accident situation most people sacrifice more money to reduce their probability of being victims of an accident rather than injurers, even under the full compensation of damages. Tort scholars should consider this behavioral bias when defining liability rules and specifically when establishing negligence standards.

As a final note on the methodology, Chapter 5 relies upon Shavell's unilateral-accident model to set the hypotheses for the experiment. It focuses on no-fault liability rules — no liability and strict liability — and the experiment uses a between-subject 2 x 2 design, whereby the treatments differ in the type of liability rule (strict liability or no liability) and the role played in an accident (victim or injurer).

Chapter 6 concludes with a discussion on the results achieved in the separate chapters and a short comment on the possible interaction between tort law and insurance in the context of liability for automated technologies. It shows and discusses how the results derived from the separate chapters combine with each-others, and suggests several insights for future research.

2. Sharing Residual Liability: "Cheapest-Cost-Avoider" Revisited[6]

"To err is human," the great poet famously wrote.[7] No doubt the tort lawyer would happily agree. It seems indeed an inescapable characteristic of human activity that accidents arise from time to time. Yet while accidents may be an inevitable part of life, we can nevertheless take steps to ensure that they are a somewhat less frequent part of it. For although accidents may not be entirely eliminable, exercising sensible precautions may at least reduce their likelihood.

The most obvious function of tort law —at least from an economic perspective— is to incentivize prospective injurers and potential victims to exercise optimal precautionary care when undertaking risky activities, balancing the cost of precautions

[6] This chapter is largely based on my paper "Sharing Residual Liability: "Cheapest-Cost-Avoider" Revisited," *Minnesota Legal Studies Research Paper No. 13-47*, coauthored with Emanuela Carbonara (University of Bologna, Department of Economics) and Francesco Parisi (University of Minnesota, Law School; University of Bologna, Department of Economics). The working paper has been revised and resubmitted to the Journal of Legal Studies. The authors would like to thank Ronen Avraham, Omri Ben-Shahar, Ennio Bilancini, Giuseppe Dari-Mattiacci, Samuel Ferey, Barbara Luppi, Ariel Porat, and Louis T. Visscher for helpful comments and suggestions, as well as seminar audiences at the 2014 Annual Meeting of the American Law and Economics Association at University of Chicago, the 2013 Annual Conference of the European Association of Law and Economics at the University of Warsaw, the 2013 Annual Meeting of the German Law and Economics Association at the Free University of Bozen, the 2013 EDLE conference at the University of Hamburg.

[7] Alexander Pope, *An Essay on Criticism* (1711).

against the expected cost of accidents.[8] Specifically, by assigning liability to "negligent" parties, the law of negligence incentivizes potential injurers to exercise optimal care under threat of liability; and recognizing that potential injurers will tend to behave non-negligently, potential victims are likewise incentivized to exercise optimal care under threat of uncompensated injury.

Yet precautionary care is not the only relevant factor in minimizing the expected cost of accidents. Reducing the magnitude or frequency of the risky activity itself also decreases the probability of accidents. For example, an individual may lower the probability of a potential car accident by taking care (e.g., driving slower and driving sober), but also by simply *driving less often*.[9] Similarly, the likelihood that a pedestrian will be hit by a car is affected not just by drivers' and pedestrians' precautions, but also by the number of miles driven and the number of road crossings during a day. Law and economics scholars have called this factor "activity level," distinguishing it from ordinary care precautions for several reasons. The distinction between "care" and "activity level" was originally articulated by Shavell (1980) and Polinsky (1980). Their insights have found followers (Landes and Posner, 1987; Shavell, 1987; Hylton, 1991; Miceli, 1997; Shavell, 2004; Cooter and Ulen, 2007), critics (Diamond, 1974; Latin, 1986; Grady, 1988; Gilles, 1992), as well as empirical researchers (Edlin and

[8] We do not mean to imply that this function was consciously recognized at the inception of tort law (see Parisi, 2001 for a historical perspective on the development of tort law). Nor do we mean to suggest that the economic interpretation of tort law is the only one, though it has become the dominant perspective (See Coleman, 1982, 1991, for alternative moral theories on tort law).

[9] The statistics tell us that the more miles you drive, the higher the chance that you will be involved in an accident (see among others the reports provided by Fatality Analysis Reporting System, National Highway Traffic Safety Administration.): by driving 10000 miles per year, the probability of being involved in an accident is approximately 10 times higher than it would be if driving only 1000 miles per year.

Mandic, 2006). Parties' care levels are generally verifiable by courts, whereas their activity levels are often more difficult to determine. Even when activity levels can be ascertained by courts, determining their optimality may be very difficult, inasmuch as the value of the parties' activities is difficult to measure by a third-party decision-maker. "Activity levels" have also been used as a catchall term for any precaution that a court will not consider when evaluating negligence. In one sense therefore, activity levels are by definition those evidentiary factors that are inaccessible or are otherwise ignored by courts. For these reasons, courts directly control parties' incentives to take precautions (i.e., by setting the standard of due care), but only exert some influence on activity levels indirectly.

Historically, liability rules were designed to incentivize potential tortfeasors and potential victims to exercise appropriate levels of care when undertaking risky activities. Under such regimes, a "negligent" party, failing to exercise due care, bears the cost of the resultant accident. Tort scholars and legal systems have largely been concerned with the scope and magnitude of liability in situations involving at least one such negligent party. Though optimal precautionary investments reduce the probability of an accident, accidents among faultless parties may still arise, and the cost of such accidents must still be borne by someone. We refer to accident liability arising when both injurer and victim acted non-negligently as "residual liability" or "residual loss" interchangeably. The allocation of residual liability is the court's lever for influencing activity-level incentives (Cooter and Ulen, 2007, p. 348; Dari-Mattiacci et al., 2014). Notably, while liability rules may succeed at incentivizing optimal care, it has been demonstrated that none of the traditional liability categories succeeds at generating optimal activity level incentives. This result is sometimes referred to as "Shavell's activity level theorem."

Until recently, tort scholars have been primarily concerned with care incentives, investigating the scope and magnitude of liability when one or more of the parties behaved negligently. The relative lack of scholarly interest in "non-negligent" accidents may be attributable to a sense of resignation that optimal activity levels are unachievable under traditional tort rules, along with concerns about the accessibility of activity level information. However, in equilibrium, prospective injurers and potential victims will both behave non-negligently, and therefore a number of the accidents that occur in reality will arise despite the due diligence of the individuals involved. We shall use the terms "diligent" and "non-negligent" interchangeably. Thus, assuming a tort regime is efficient with respect to precautionary care, the question how we deal with such non-negligent accidents takes on acute significance, and unsurprisingly a growing body of recent research has been directed toward this topic (Gilles, 1992; Calabresi, 1996; Calabresi and Cooper, 1996; Parisi and Fon, 2004; Dari-Mattiacci and De Geest, 2005; Parisi and Singh, 2010; Garoupa and Ulen, 2013; Dari-Mattiacci et al., 2014).

In dealing with non-negligent accidents, tort regimes have traditionally adopted "all-or-nothing" approaches, whereby the accident losses are assigned either entirely to the tortfeasor or entirely to the victim, with no possibility of division. Under negligence-based rules—simple negligence, contributory and comparative negligence—the victim must absorb the residual loss (i.e. the loss that occurs when both parties are non-negligent), while under strict-liability-based rules—strict liability, and strict liability with a defense of dual contributory negligence, contributory negligence, and comparative negligence—the injurer bears the residual loss. Briefly, negligence-based rules burden the victim, while strict-liability-based rules burden the injurer with the cost of faultless accidents (see Cooter and Ulen (2007) and Dari-Mattiacci and Parisi (2013) for a comprehensive taxonomy of liability rules). This chapter analyzes the conditions under which loss-sharing proves to be more effective than conventional all-or-nothing liability regimes in minimizing accident losses. We will proceed by relaxing the standard assumptions used in earlier tort models. The critical analytical move will be to unbundle Calabresi's (1970) "cheapest-cost-avoider" principle to distinguish specific situations where the sharing of the loss generates superior activity-level incentives. We show that the allocation of residual loss has non-trivial consequences on a number of additional variables. This suggests that, even in a world in which all relevant actors are risk-neutral, the optimal allocation of residual liability should play an important role in the normative choice of tort liability.

This chapter is structured as follows. Section 2.1 provides a review of the existing literature on loss-sharing between non-negligent parties. Section 2.2 sets up a simple tort model to compare loss-sharing and all-or-nothing liability as alternative second-best solutions in allocating an accident loss between a non-negligent tortfeasor and his non-negligent victim. Section 2.3 discusses the conditions under which loss-sharing in equilibrium may prove to be superior to conventional liability rules in affecting second-best activity levels. This study proceeds analytically by unpacking the cheapest-cost-avoider principle into a number of sub-principles, namely the least-risk-producer, the cheapest-activity-avoider, the cheapest-risk-avoider, the best mix of activities, the best scale of activities and the best-risk-bearer.[10] The results show that the choice between liability rules depends on the interaction of these factors, and that loss-sharing rules become more appealing in the presence of countervailing policy objectives and homogeneous conditions of risk. More specifically, loss-sharing is desirable not only when parties are risk-averse but also when parties are risk-neutral. In case of risk-averse parties, loss-sharing plays a mutual insurance role, placing a greater portion of the risk on the best risk-bearer. Interestingly, as pointed out in the recent law and economics literature, the sharing of non-negligent losses provides a form of risk-spreading that avoids the dilution of incentives and the moral hazard problems caused by standard liability insurance (Parisi and Fon, 2004; Parisi and Singh, 2010; Dari-Mattiacci et al., 2014). Loss-sharing can also yield second-best activity-level incentives when parties are risk-neutral, as it encourages higher activity levels by more productive and less risky parties, which enhances social welfare. This chapter unveils several important policy considerations in assigning the optimal allocation of residual risk. Section 2.4 concludes by offering a condensed summary of our results and a brief discussion of their significance.

[10]The current literature refers to several factors encompassed in the cheapest-cost-avoider principle, including cheapest risk-avoider, cheapest precaution-taker, best risk-bearer, and most effective precaution-taker. For a complete list of these factors with brief analytical definitions, see Parisi (2013).

2.1 Residual Loss-Sharing: Related Literature

The adoption of optimal precautions is not a panacea against accidents. When both parties undertake due care, an accident may nevertheless occur, and someone ultimately needs to bear the accident loss. Since Shavell (1980), scholars generally refer to such faultless accident loss as "residual loss" or "residual liability." Traditionally, legal rules assign the entire residual loss either on the victim (negligence rules) or on the tortfeasor (strict-liability rules). Residual loss-sharing rules would instead allow a sharing of the residual loss when neither party is at fault. In Table 2.1 we illustrate the allocation of the accident loss under residual loss-sharing, comparing it to a traditional rule of comparative negligence. In a comparative negligence regime, accident losses are shared when both parties are negligent (Table 2.1, Panel (a)). In a comparative non-negligence regime, accident losses are instead shared when neither party is negligent (Table 2.1, Panel (b)). Hereinafter, we shall refer to this latter form of loss-sharing as "Residual Loss-Sharing."

(a) Loss-Sharing Between Negligent Parties

		Injurer	
		Negligent	*Diligent*
Victim	*Negligent*	**Share**	Victim
	Diligent	Injurer	Victim

(b) Residual Loss-Sharing Between Non-Negligent Parties

		Injurer	
		Negligent	*Diligent*
Victim	*Negligent*	Injurer	Victim
	Diligent	Injurer	**Share**

Table 2.1: *Loss-Sharing vs. Residual Loss-Sharing*

Unlike negligent-based accidents, for which losses are often split between negligent parties — as under comparative negligence (Panel (a) in Table 2.1: "Loss-Sharing

Between Negligent Parties"), it is rare cases that tort systems have used loss-sharing rules between non-negligent parties, through comparative non-negligence rules (Panel (b) in Table 2.1: "Residual Loss-Sharing Between Non-Negligent Parties"). In modern legal systems, loss-sharing rules are applied by courts when it is undesirable or prohibitively expensive to compare fault. Similarly, in international law loss-sharing and indemnification rules are adopted for catastrophic events among sovereign states. So for example, loss-sharing rules have been adopted in U.S. jurisdictions to spread an accident loss between an incapable child (who was deemed incapable of being at fault) and the owner of a dog, who had taken reasonable precautions (*Howard v. Allstate Insurance Co*);[11] between a municipality and a truck driver for an accident occurred due to poor road conditions (*Gibson v. State ex rel. Department of Transportation and Development*);[12] between an employee and the Commission of the European Communities for his wrongful arrest (*Stanley George Adams v. Commission*).[13] More specifically, recent examples of loss-sharing solutions in U.S. case law include *Howard v. Allstate Insurance Co.*,[14] a well-known Louisiana case, in which the defendants were found non-negligent but were nevertheless held "partially liable" when their dog bit a child. The court implemented a loss-sharing solution introducing a sort of "comparative non-negligence" rule, according to which the plaintiffs' non-negligent conduct is compared to the defendants' non-negligent conduct (the victim was a mentally dis-

[11] 520 So. 2d 715 (La. 1988).
[12] 674 So. 2d 996 (La. Ct. App. 1996).
[13] Case 145/83, Stanley George Adams v. Commission, 1985 E.C.R. 3651, 45 C.M.L.R.506, 550 (1986).
[14] 520 So. 2d 715, 719 (La. 1988).

abled child, whose fault could not be easily assessed), in order to determine how to split the loss between the parties. Similarly in products liability, courts have occasionally adopted loss-sharing in the absence of comparative negligence criterion. Courts use residual loss-sharing as a way to spread losses between producers and consumers. See for example *Murray v. Fairbanks Morse*.[15] In several other U.S. cases, courts apportioned the loss among faultless parties on a causal basis as a loss-spreading solution when no other criterion of liability allowed to split the loss between the parties. See for example *Gibson v. State ex rel. Department of Transportation and Development*.[16] Similar developments of the loss-sharing alternative can be found outside of the U.S. For example, Japanese courts have adopted equitable loss-sharing solutions in both tort and contract cases. Japanese courts exercise substantial discretion in considering the individual circumstances of a particular case to determine the liability of the defendant (Yu, 2000). As discussed in Yoshihsa (1999), this judicial discretion provided a pragmatic adjudicatory solution in several mass toxic tort cases, in which there was an unclear causal connection between the defendant's poisoning and the resulting illness. Legal developments in Europe have also focused on loss-sharing in the field of environmental law. The *Hoge Raad*, the Supreme Court of the Netherlands applied loss-sharing solutions to a series of cases involving environmental liability in the 1980s.[17] Both the law of the European Union and public international law follow a similar ap-

[15] 610 F.2d 149, 158 (3d Cir. 1979).

[16] 674 So. 2d 996 (La. Ct. App. 1996).

[17] For further references on the Dutch trends, see Hondius (1999). Loss-sharing rules are also adopted in divorce law for breach of marriage contracts, and in labor law for employment contract breach or termination (Dari-Mattiacci and De Geest, 2005).

proach. For example, in *Stanley George Adams v. Commission*,[18] the European Court of Justice decided a case against the Commission of the European Communities for wrongful arrest, affirming that an equitable loss-sharing (with partial compensation to the plaintiff) was appropriate under the circumstances. In international law, the liability of sovereign nations for non-negligent tortious harm is governed by a loss-sharing rule with an equitable apportionment of the loss between states (Brownlie, 1990, p.434). Diplomatic expediency often reinforces the need to adopt loss-sharing in the absence of fault, in order to maintain good foreign relations and uphold the principle of reparation (Brownlie, 1990, p.439).

In legal theory, fourteenth-century commentators and fifteenth-century legal humanists considered explicitly the problem of apportioning losses among faultless parties. Seventeenth-century natural law scholars such as Hugo Grotius (1583-1645) and Samuel Pufendorf (1632-1694) took a clear position in favor of residual loss-sharing, criticizing the so-called fault principle and formulating an alternative paradigm of liability, which they called the principle of compensation. Grotius (1625) proposed moving away from the fault principle suggesting that, absent fault, there was no reason to let losses fall on the innocent victims, just as there was no obvious reason to shift the entire accident loss on the tortfeasor. The essence of their arguments was that when neither party is negligent or when negligence cannot be assessed, equitable principles may warrant a sharing of the residual loss between the parties. American tort scholars have expressed support for the idea of residual loss-sharing, arguing that

[18]Case 145/83, 1985 E.C.R. 3651, 45 C.M.L.R. 506, 550 (1986).

we must recognize the possibility that strict liability is a sliding scale and not an exact point of reference (Palmer, 1988, p. 1306). Loss-sharing is therefore often regarded as a logical alternative to the "unfair" all-or-nothing allocations of liability for faultless accidents (Gershonowitz, 1986, p. 485). Also Grimley (2000, p. 534) and Strassfeld (1992, p. 949) discussed several arguments in favor of loss-sharing among faultless parties. Loss-sharing in tort has been advocated also in other formulations, for example through comparative negligence in the presence of negligent parties (see Bar-Gill and Ben-Shahar, 2003 for a recent critical review of related literature), of several potential tortfeasors (Landes and Posner, 1980; Kornhauser and Revesz, 1989, 1990, 1994), of asymmetric costs of precautions (Rubinfeld, 1987), or under conditions of evidentiary uncertainty (Dari-Mattiacci and De Geest, 2005), and through proportional liability in the presence of causal uncertainty (Young et al., 2004).

Notwithstanding these historical antecedents, only a handful of law and economics scholars have given attention to the possibility of residual loss-sharing. Calabresi (1965, 1970) was the first to consider the value of deterring accidents between faultless parties. Calabresi (1965) first observed that systems that apportion liability based on fault only deter those accidents that are caused through fault and ignore the value of deterring accidents that are faultless. In his later book, Calabresi (1970) returned to this issue, assessing the merits of loss-sharing between faultless parties. Calabresi stated that "the justification found most often among legal writers today for allocation of accident losses on a nonfault basis, is that accident losses will be least burdensome if they are spread broadly among people and over time" (Calabresi, 1970, p.

39). A quarter of a century later, Calabresi (1996) and Calabresi and Cooper (1996) lamented that not enough consideration had been given to the idea of distributing the loss between non-negligent parties and explored the idea put forth in Calabresi's earlier writings in greater detail. Calabresi and Cooper (1996) stressed the desirability of splitting losses among faultless parties instead of having a legal rule in place that puts the entire burden on either the plaintiff or the defendant. Calabresi's arguments in favor of residual loss-sharing ran against the conventional wisdom in the law and economics literature, according to which any form of loss-sharing would be undesirable because it would dilute care-level incentives (Brown, 1973). Recent contributions reconciled the two opposing views, showing the limits of the conventional wisdom. The concern that loss-sharing may dilute incentives is correct as a general matter, but is not applicable when loss-sharing is carried out only with respect to non-negligent parties (i.e., residual loss-sharing). Recent research in the law and economics literature suggests that a spreading of the residual loss in equilibrium can be accomplished preserving efficient care incentives. The first contribution that studied the incentive effect of residual loss-sharing is Parisi and Fon (2004). The authors showed that residual loss-sharing does not necessarily undermine care-level incentives while studying the effects of a rule of comparative causation (a species of residual loss-sharing in which liability is divided between faultless parties on the basis of their causal contribution to the accident). Parisi and Fon (2004) never derived a general proof, and their model showed that loss-sharing in the form of comparative causation under negligence was in most cases compatible with full incentives for optimal care. Parisi and Singh (2010) later provided a more general proof of the compatibility of residual loss-sharing under comparative causation with optimal care incentives.[19] In the latest contribution to the topic, Dari-Mattiacci et al. (2014) showed that, under some sufficient conditions, parties' compliance with the standard of due care can be achieved in equilibrium not only for any residual loss-sharing rule implemented among negligent parties (Landes and Posner's 1980 result), but also for any loss-sharing rule implemented among non-negligent parties. In Dari-Mattiacci et al. (2014), the plausible conditions under which compliance with the standard of due care is a Nash equilibrium are the following: the standards of due care and the loss-sharing rule are set at the (second best) socially optimal levels; a party's (optimally chosen) activity level decreases in his due-level of care (i.e., an increase in a party due-care level reduces his chosen level of activity). In their Section 3, Dari-Mattiacci et al. (2014) analyzed the optimal setting of residual loss-sharing in a specification of their initial general model, where parties' activity levels are independent of each other in the production of the expected accident loss. They further restricted the analysis by using two functional forms of the loss function, i.e., a linear and a quadratic loss function. This chapter generalizes and extends Dari-Mattiacci et al.'s (2014, Section 3) analysis in considering a more general model without employing specific functional forms in order to investigate different interrelations of parties' activities in the production of the expected accident loss (Section 2.3.4).

Building on a generalization of these results, this study tackles two novel, interre-

[19]For an analysis of the effects of liability rules on parties' care incentives, see also Landes and Posner (1983), Haddock and Curran (1985) and Singh (2006).

lated questions. While Parisi and Fon (2004), Parisi and Singh (2010), Dari-Mattiacci et al. (2014) established the independence of the residual liability problem, they never investigated *when* and *how* loss-sharing rules ought to be employed. This chapter investigates what factors should guide the optimal allocation of residual liability and under which conditions residual loss-sharing among faultless parties may be preferable to conventional all-or-nothing rules. We identify several characteristics of parties' activities and accident functions which should optimally guide the apportionment of the residual loss. We relate these characteristics to Calabresi's (1970) "cheapest cost-avoider" principle, identifying six sub-principles that are embedded in the cheapest-cost-avoider principle. Specifically, we offer a more generalized accident model to consider *all* possible relationships between the riskiness and the value of activities, the interaction of the parties' activities in the production of risk, returns to scale from the activities, and parties' relative risk preferences. The analysis of these factors, considered in isolation and collectively, allows us to understand under which conditions loss-sharing rules are preferable to conventional all-or-nothing rules. It is worth noting that other authors analyzed the heterogeneities among parties and their activities in independent, yet related studies. Emons (1990a) and Emons and Sobel (1991) first analyzed liability rules when risk-neutral parties have different marginal utilities from their actions. They argued that sharing-liability rules implement a superior allocation of the activity levels compared to negligence rules. Garoupa and Ulen (2013) questioned one of the implicit assumptions regarding the activity-level effect, namely the positive monotonic relationship between the probability of accident and the risky activity. The authors pointed out definitional issues on activity level, and discussed the complementary role of liability and regulation in incentivizing socially optimal precautions. These contributions can find a formal extension and a deeper analysis on other sources of heterogeneity among tortious activities, in our research.

2.2 The Model: Setting the Stage

Let us begin by defining terms and articulating our assumptions. We consider a bilateral non-durable care model in which two parties—the potential tortfeasor (T) and the potential victim (V)—influence the unilateral risk of an accident (i.e., where only the victim suffers the loss if an accident occurs) by taking two different types of precautionary measures: care level and activity level.

Following the conventional notation, x and y denote the tortfeasor's and victim's care levels respectively, and z and u denote the tortfeasor's and victim's activity levels respectively. Let $w = w(z,x)$ be the injurer's level of wealth, and let $b = b(u,y)$ be the victim's wealth. We begin adopting the standard assumptions of tort models (Landes and Posner, 1987; Shavell, 1987; Miceli, 1997; Dari-Mattiacci et al., 2014): both parties' utilities decrease in care level at a constant or increasing rate, and increase in activity level at a decreasing rate, i.e., $w_x < 0$, $w_{xx} \leq 0$, $w_z > 0$ and $w_{zz} < 0$ for the tortfeasor, whereas $b_y < 0$, $b_{yy} \leq 0$, $b_u > 0$ and $b_{uu} < 0$ for the victim. We shall relax some of these assumptions in Section 4.5 to consider the effect of increasing returns, i.e., $w_{zz},\ b_{uu} > 0$, on the optimal allocation of residual liability. We plausibly assume that an increase in a party due-care level reduces his optimally chosen level of activity.[20]

We now turn to the cost of accidents. Following the conventional setup (Shavell, 1980, 1987), we assume that the probability of an accident $q(z,u)$ increases at a constant or increasing rate as parties increase their activity levels, i.e., q_z, $q_u > 0$, q_{zz}, $q_{uu} \geq 0$, and that the loss suffered by the victim in the event of an accident $L(x,y)$ decreases in care levels at a decreasing rate, i.e., L_x, $L_y < 0$, L_{xx}, $L_{yy} > 0$. The assumption that the probability of the accident loss is not affected by care levels comes without loss of generality: the same results are achieved by defining the expected accident loss as a function of all the four decision variables, i.e., $D = D(x,y,z,u)$. Following Dari-Mattiacci et al. (2014), we consider parties' activities as independent in the production of the accident loss, i.e., $q_{zu} = 0$. We shall relax this assumption in Section 4.4 to consider cases where parties' activities are substitutes, $q_{zu} > 0$, or complements, $q_{zu} < 0$. Dari-Mattiacci et al. (2014, Section 3) assumed the loss function to have an additive form, that is, the parties' activity levels are independent of each other in the production of the expected accident loss. Our general formulation allows to extend the framework in Dari-Mattiacci et al. (2014, Section 3) to consider different interaction of parties' activity choices in the production of the expected accident loss (see Section 2.3.4).

The share of the residual loss borne by the injurer is denoted by σ, such that $0 \leq$

[20] The definition of due-care standards influences parties' activity choices and might change depending upon the interrelation between care and activity levels. The standard accident model assumes the cost of care to be proportional to activity level (Shavell, 1987, 2004). Nussim and Tabbach (2009) relaxed this assumption within a unilateral-accident model and analyzed the impact of different interactions between the injurer's care and activity levels on the definition of due-care standards.

$\sigma \leq 1$. In other words, σ represents the allocation rule for accident losses in the absence of fault. In the limiting cases, $\sigma = 0$ is the allocation produced by a negligence rule, $\sigma = 1$ is the allocation produced by a strict-liability rule, while $0 < \sigma < 1$ is the allocation produced by a residual loss-sharing rule.

The optimization problem is formulated as a two-stage problem where the choice of activity levels in the second stage is affected by the initial-stage definition of the liability rule σ by the social planner. The model is thus solved by backward induction. We consider the case of risk-neutral agents, and we discuss some special insights related to the case of risk-averse agents in Section 2.3.6.

Under the assumptions specified in Section 2.2, it can be shown that parties have incentives to comply with the due-care standards regardless of the sharing rule among negligent parties.[21] Thus the following lemma holds true throughout our analysis:

Lemma 2.2.1 (Loss-Sharing Neutrality)**.** *Under any fault-based liability rule, if due-care standards and the loss-sharing rule among non-negligent parties are set at the (second best) socially optimal level, parties have optimal incentives to comply with the due-care standards $x^* = x^{d*}$ and $y^* = y^{d*}$ regardless of the loss-sharing rule implemented among negligent parties.*

Proof. See Appendix 2.5. □

Given that under Lemma 2.2.1 compliance with due care standards is verified for

[21]It has already been established in the recent literature that under any fault-based liability rule, if due-care standards and the loss-sharing rule among non-negligent parties are set at the (second best) socially optimal level, parties have optimal incentives to comply with the due-care standards, regardless of the loss-sharing rule implemented among negligent parties (Singh, 2006; Dari-Mattiacci et al., 2014).

any chosen sharing rule, we can meaningfully restrict our analysis to the properties of the equilibrium in the region of $x^* = x^{d*}$ and $y^* = y^{d*}$. This allows us to focus on the characterization of the optimal sharing rule. The first-stage (second best) social maximization problem can be expressed as follows:

$$\max_{x^d, y^d, \sigma} S = w(z,x) + b(u,y) - q(z,u)L(x,y) \tag{2.2.1}$$

$$\text{subject to } x^* = x^{d*} \text{ and } y^* = y^{d*} \tag{2.2.2}$$

$$z^* = z(x^{d*}, y^{d*}, \sigma^{**}) \text{ and } u^* = u(x^{d*}, y^{d*}, \sigma^{**}) \tag{2.2.3}$$

The social planner maximizes the social welfare function (2.2.1) subject to two constraints. Constraint (2.2.2) indicates that parties have incentives to comply with the due care standards, as shown in Lemma 2.2.1. Constraint (2.2.3) indicates that the privately optimal activity choices depend upon all policy variables.

The non-negligent tortfeasor and his faultless victim will choose the activity levels which maximize their utility functions, i.e.,

$$\max_z U_T = \; w(z, x^{d*}) - \sigma q(z,u)L(x^{d*}, y^{d*}) \tag{2.2.4}$$

$$\max_u U_V = \; b(u, y^{d*}) - (1-\sigma) q(z,u)L(x^{d*}, y^{d*}) \tag{2.2.5}$$

The privately optimal activity levels z^* and u^* are respectively defined as follows (omitting arguments):

$$w_z - \sigma\, q_z\, L = 0 \tag{2.2.6}$$

$$b_u - (1-\sigma)\, q_u\, L = 0 \tag{2.2.7}$$

The second-best socially optimal loss-sharing rule, σ^{**}, and the second-best socially optimal due-care levels, x^{d*} and y^{d*}, are respectively defined as follows:

$$\frac{dz^*}{d\sigma}\,(w_z - q_z L) + \frac{du^*}{d\sigma}\,(b_u - q_u L) = 0 \tag{2.2.8}$$

$$\frac{dz^*}{dx^d}\,(w_z - q_z L) + \frac{du^*}{dx^d}\,(b_u - q_u L) + w_x - qL_x = 0 \tag{2.2.9}$$

$$\frac{du^*}{dy^d}\,(b_u - q_u L) + \frac{dz^*}{dy^d}\,(w_z - q_z L) + b_y - qL_y = 0 \tag{2.2.10}$$

By considering (2.2.6) and (2.2.7), the second-order effects of marginal changes in σ on the privately optimal activity levels are given by:

$$\frac{dz^*}{d\sigma} = \frac{q_z L}{w_{zz} - \sigma q_{zz} L} \tag{2.2.11a}$$

$$\frac{du^*}{d\sigma} = -\frac{q_u L}{b_{uu} - (1-\sigma) q_{uu} L} \tag{2.2.11b}$$

Similarly, the second-order effects of marginal changes in the due-care levels on the privately optimal activity levels are given by:

$$\frac{dz^*}{dx^d} = \frac{-w_{zx} + \sigma q_z L_x}{w_{zz} - \sigma q_{zz} L} \tag{2.2.12a}$$

$$\frac{du^*}{dx^d} = \frac{(1-\sigma) q_u L_x}{b_{uu} - (1-\sigma) q_{uu} L} \tag{2.2.12b}$$

$$\frac{dz^*}{dy^d} = \frac{\sigma q_z L_y}{w_{zz} - \sigma q_{zz} L} \tag{2.2.12c}$$

$$\frac{du^*}{dy^d} = \frac{-b_{uy} + (1-\sigma) q_u L_y}{b_{uu} - (1-\sigma) q_{uu} L} \tag{2.2.12d}$$

The optimal levels of due-care standards (5.2.2) and (2.2.10), and the second-order effects in (2.2.12) show that changes in $\sigma \in [0,1]$ affect the definition of the due-care standards, x^{d*} and y^{d*}, but parties' compliance with such due-care standards is not undermined, as shown in Lemma 2.2.1. Our analysis considers how the injurer's share of the residual loss should optimally change within the non-negligence region of $x^* = x^{d*}$ and $y^* = y^{d*}$. In other words, we focus on the optimal allocation of the residual loss as defined in (2.2.8). Our general framework allows to identify all the possible interrelationships between the policy variables and activity levels. Future research can build on this framework to study the conditions under which second-best efficiency would require either varying the allocation of the residual loss, or changing the due-care standards, or both.

2.3 Optimal Loss-Sharing: Unbundling the “Cheapest-Cost-Avoider”

This section analyzes the optimal value of σ, as given by (2.2.8), to identify the conditions under which loss-sharing could be desirable and more efficient than conventional all-or-nothing liability rules. We will consider several factors in isolation, exploring the optimal assignment of residual liability when a particular factor is determinative. The interaction of factors and their significance are then discussed in Section 2.4.

2.3.1 Riskiness of the Activity: “Least Risk-Producer”

The first building block in our analysis sheds light on the riskiness of the activity, defined as the marginal increase in the probability of an accident when either the injurer or the victim increase their activity level (i.e., q_i, $i = z,\ u$). Bracketing off other factors, the relative riskiness of the activity may also determine the optimal allocation of the residual loss, as identified in Proposition 2.3.1.

Proposition 2.3.1. (Least Risk-Producer). *Ceteris paribus, when the injurer’s activity is substantially riskier than the victim’s, strict-liability rules are preferable. When the victim’s activity is substantially riskier than the injurer’s, negligence rules are preferable. When the parties’ activities present similar riskiness, loss-sharing rules are socially desirable. Particularly, when activities are equally risky it is optimal that parties* *share the loss in equal measure.*

Proof. See Appendix 2.5. □

Intuitively, if the activity of the injurer is more likely to increase the probability of an accident with respect to the activity of the victim, it is preferable to shift a larger portion of the residual loss on the tortfeasor. When the injurer's activity is substantially riskier, the adoption of a strict-liability rule may be warranted. Clearly, for activities of comparable value, the net value of a dangerous tortfeasor's activity is smaller because it creates a greater expected accident loss. Consequently, from a social point of view, reductions in such dangerous activities will be less costly than reductions in less harmful activities. The converse holds true when the victim's activity poses the greater risk. And in both cases, all-or-nothing liability systems are preferable to a loss-sharing rule. This may explain the adoption of strict liability in cases involving abnormally dangerous (or "ultrahazardous") activities —e.g., transportation of dynamite and other explosives— and the use of no-liability regimes to mitigate victim's extraordinary exposures to risk —e.g., less-skilled skiers facing the hardest slopes; cyclists riding in high-speed roads (see for example the Italian legal system in which under certain conditions drivers are immune from liability for accidents involving pedestrians or cyclists in highways)[22].

As regards ultrahazardous activities, according to the Restatement (Second) of Torts, §520: "In determining whether an activity is abnormally dangerous, the following factors are to be considered: (a) existence of a high degree of risk of some harm

[22]Cass. Pen. , Sez. IV, n. 33207 31 luglio 2013.

to the person, land, or chattels of others; (b) likelihood that the harm that results from it will be great; (c) inability to eliminate the risk by the exercise of reasonable care; (d) extent to which the activity is not a matter of common usage; (e) inappropriateness of the activity to the place where it is carried on; and (f) extent to which its value to the community is outweighed by its dangerous attributes." Several categories of activities are commonly defined as ultrahazardous, including transportation, storage, and use of dynamite and other explosives, radioactive materials, and hazardous chemicals; keeping of wild animals or domesticated animals that have a known propensity for dangerous behavior (e.g., keeping a domesticated animal that has attacked people before). Ultrahazardous activities are classified as a strict liability tort, i.e., the person performing the activity can be held liable, even if she took reasonable precautions to prevent harm. Examples from case law of absolute liability for ultrahazardous activities are *Rylands v. Fletcher*,[23] *Arvidson v. Reynolds Metals Co.*,[24] *Langan v. Valicopters, Inc.*.[25] For a general overview of these and other related cases, see James, 1949.

The result in Proposition 2.3.1 is consistent with Cooter and Ulen (2007, p. 349): "Usually one party's activity level affects accidents more than the other party's activity level. Efficiency requires choosing a liability rule so that the party whose activity level most affects accidents bears the residual costs of accidental harm." This section extends Cooter and Ulen (2007)'s intuition by showing that sharing rules might be the preferred option when one party's activity is riskier but relative riskiness is not substantially

[23](1866) UKHL 1, LR 3 HL 330, (1868) LR 3 HL 330.
[24]107 F. Supp. 51 (W.D. Wash. 1952).
[25]567 P.2d 218, 88 Wash. 2d 855, 88 Wash. 855 (1977).

different. In other words, all-or-nothing rules are optimal when one party's activity is far riskier than the other party's activity.

Concerns of practical implementability may arise with respect to the application of this proposition, except when courts and juries can discern the relative difference in the riskiness of parties' activities.

2.3.2 Value of the Activity: "Cheapest Activity-Avoider"

The next building block for the understanding of the optimal allocation of residual liability comes from the value of the parties' activities. Accidents are often the unavoidable byproduct of otherwise desirable human activities. However, not all activities are equally desirable. The optimal liability rule, ceteris paribus, should make the party who can reduce the activity level at the lowest cost ("cheapest activity-avoider") the residual bearer of the accident loss. The cheapest activity-avoider entails consideration of the relative value of the parties' activities.

Clearly, the reduction of a more valuable activity will reduce social welfare more than the reduction in a less valuable activity. Thus, all things being equal, residual liability should fall on the party that can reduce its activity level at a lower social cost.

Proposition 2.3.2. (Cheapest Activity-Avoider). *Residual liability should fall on the party who can more cheaply reduce his or her activity level. Ceteris paribus, when the injurer's activity is substantially more valuable than the victim's, negligence rules are desirable. When the victim's activity is substantially more valuable than the injurer's, strict-liability rules are desirable. When the parties' activities have comparable val-*

ues, loss-sharing rules are preferable to all-or-nothing allocations. Particularly, when activities are equally valuable, it is optimal for parties to share the loss in equal measure.

Proof. See Appendix 2.5. □

A reduction in the level of activity results in a reduction in the probability of an accident, but also a decrease in the total value of the activity. All things being equal, the cost of non-negligent accidents should be borne by the individual who undertakes the less valuable activity, because a reduction in activity level will be less costly from a social point of view. A close variant of the idea that residual liability should be borne by the party who more cheaply reduce his or her activity level can be found in Cooter and Ulen (2007). As already mentioned, the idea that losses can be shared expands the domain of possibilities, compared to the conventional all-or-nothing approach. For example, efficiency should favor the activity of a doctor who needs to drive to visit his patients over somebody who uses his car to distribute marketing ads. If liability rules could be linked to some observable characteristics such as profession (or other proxy for the value of the activity), then it might be possible to efficiently allocate the residual loss based on the relative values of the parties' activities. This result may also provide a positive explanation for the heightened standard of liability (i.e., gross negligence or intent is required for liability) when socially valuable activities such as ambulance driving or firefighting are involved. For example, in *Wilkins v. Williams*,[26] a motorist was injured in a traffic accident with an ambulance and was hospitalized. The motorist

[26] 991 N.E.2d 308, 2013 I.L. 114310, 372 Ill. Dec. 1 (2013).

filed a negligence claim against the ambulance driver individually and as agent of the ambulance service and the ambulance service. The Supreme Court of Illinois held that the Emergency Medical Services Act provides emergency medical service providers immunity from civil liability based on the provision of emergency or non-emergency medical services in the normal course of conducting their duties except in cases of willful and wanton misconduct (see Medical Law Perspectives, February 2013 Report: "Emergency Medical Services: Liability and Immunity for Medical Rescue"). As regards immunity from liability for fire police officers, see for example § 9-1-27 Police and firefighters, Immunity from liability (RI Gen L § 9-1-27 (2013)): "No member of any police force or fire department of the state or any city or town, [...], or any person acting in the capacity of a rescue attendant or member of a rescue squad, and no officer or member in active service in any incorporated protective department cooperating with fire departments, and no person performing the duties of a firefighter in a town or city, and no member of any volunteer fire company or volunteer rescue squad or member of any voluntary ambulance association, whether the company or squad is incorporated or not, who while on duty and in the performance of that duty voluntarily and gratuitously renders emergency assistance to a person in need thereof, and no person properly certified by the American heart association or the American national red cross in basic or advanced life support as defined in the standards of the American heart association or the American national red cross who voluntarily and gratuitously renders emergency assistance to a person in need thereof shall be liable for civil damages for any personal injuries or property damage which result from acts or omissions by the persons rendering the emergency care, which may constitute ordinary negligence. This immunity does not apply to acts or omissions constituting gross, willful, or wanton negligence."

2.3.3 Trading Off Riskiness and Value of the Activity: "Cheapest Risk-Avoider"

When applying the cheapest-cost-avoider criterion in the context of Calabresi's (1970) paradigm, it is especially important to consider the interaction between the factors we analyzed above. If the activity of the injurer is socially more valuable but at the same time riskier than the victim's activity, then a trade-off arises: if an all-or-nothing approach is used, one of the parties will either carry on a riskier or a less valuable activity with greater-than-optimal intensity. Loss-sharing rules may offer a more desirable alternative in such cases. To illustrate the point, consider a collision (due to bad weather, hectic traffic, congestion or poor visibility) between a car and a truck. The collision occurs even though both drivers have taken the due precautions (e.g., observing speed limits, stopping at the stop sign), and only the car is damaged. Consider the case in which the truck driver's activity is socially more valuable, but at the same time creates a greater risk than the car. If a negligence rule applies (as efficiency would require when looking at the value of the activity), the truck driver will undertake higher activity levels, notwithstanding the fact that truck driving creates a greater risk. If instead a strict-liability rule applies (as efficiency would require when looking at the riskiness of the activity), then the car driver would carry out an excessive activity level, notwithstanding the lower social value of his activity. In this case, a loss-sharing rule can usefully balance the two countervailing efficiency criteria — the least-risk-producer and the cheapest-activity-avoider — in line with a more nuanced efficiency criterion. We refer to this combined rationale as the "cheapest risk-avoider".

The major theoretical conclusion that emerges from the trade-off between the riskiness and the value of activities can be summarized in the following proposition:

Proposition 2.3.3. (Cheapest Risk-Avoider). *Ceteris paribus, when the injurer's activity is substantially less risky and at the same time more valuable than the victim's, then negligence rules are preferable. When the victim's activity is substantially less risky and at the same time more valuable than the injurer's, then strict-liability rules are preferable. When one party's activity is more valuable but at the same time riskier than the other, loss-sharing rules are preferable to both negligence and strict liability.*

Proof. See Appendix 2.5. □

2.3.4 Coordinating Risks: "Best Mix of Activities"

One often overlooked function of residual liability is that of promoting coordination among risky activities. The optimal allocation of activity-level incentives hinges upon the relationship between the parties' activities in the production of an accident loss. Here we distinguish three possible cases: *additive*, *subadditive*, and *superadditive* risks. Parties' activities create an *additive* risk, $q_{zu} = 0$, when each activity independently affects the probability of an accident, with no additional interactive effect when both parties' activities are carried out. The overall risk of an accident is determined by the sum of the parties' activities, regardless of which party carries out the larger share of the activity. Similar to independent inputs in a production function, activities that create additive risks contribute linearly to the overall risk of an accident. Given that the parties' activities independently affect the probability of an accident, any allocation of the residual loss is compatible with the social optimum. When risks are additive, the choice between negligence, strict liability, and loss-sharing solutions is driven by the other efficiency considerations discussed in the previous sections.

In real life tort situations, however, risks are rarely independent and linearly additive. The allocation of residual loss acquires acute importance when risks are interdependent, $q_{zu} \neq 0$. A first case of non linearity is the one in which parties' activities create a *superadditive* risk, $q_{zu} < 0$: raising the level of activity of one party leads to an increasing marginal augmentation of the risk. Consider, for example, the emission of chemicals and noise in the environment. The presence of moderate quantities of the two pollutants may be less harmful than the presence of high levels of only one pollutant. The risk created by additional units of pollutants may have superadditive effects. Legal systems might tackle these situations through regulation (e.g., by putting caps on the maximum quantity of each risky input) or through tort law, by spreading activity-level incentives between the parties. In this case, a loss-sharing rule might help reduce the expected accident costs, by inducing both parties to mitigate their activity levels.

A second case of non linearity is the one in which parties' activities create a *sub-additive* risk, $q_{zu} > 0$: both activities contribute to cause the accident, and total harm is greater when both parties carry out their activities conjunctly. Similar to complementary inputs in a production function, activities that create a subadditive risk contribute non-linearly to the overall risk of an accident. The resulting risk is not determined by the sum but by the relative mix of the parties' activities. Mixing different activities creates a greater risk than concentrating only one or the other activity. Consider, for example, the presence of children and cyclists on a trail. The frequency of accidents grows larger as the two activities mix together: having all children or all cyclists is preferable than having the two activities mixed together. Legal systems might tackle these situations either by separating complementary activities through regulation (e.g., planning pedestrian areas; denying access to pedestrians, bicycles and other slow vehicles in the highways; locating smokestacks industries far from residences) or through tort law, by allocating the residual liability entirely on one or the other one party. In this case, all-or-nothing rules are preferable to loss-sharing rules since they produce a result that mimics the one achieved by regulation, inducing one of the two individuals to reduce his or her activity level to a minimum.

Proposition 2.3.4. (Best Mix of Activities). *Ceteris paribus, loss-sharing rules are more efficient when parties' activities create a superadditive risk. All-or-nothing allocations of the residual loss might be preferable with subadditive risks.*

Proof. See Appendix 2.5. □

Proposition 2.3.4 may explain the dominance of all-or-nothing rules in situations characterized by subadditive risk. For example, in a shooting range area, there should be no individual walking around the target area; and in an urban environment, there should be no one shooting targets. In the case of subadditive risk, the optimal equilibrium is characterized by corner solutions: no walking in shooting rings, no shooting in walking areas. On the contrary, when risks are superadditive, high concentrations of risky activities may be problematic, and the optimal equilibrium is characterized by an interior solution with a balanced mix of different activities. In these straightforward cases, regulation of the activities can accomplish a complete separation or a mix of activities (e.g., pedestrian areas, no bicycles on highways). However, in situations that are not amenable to regulation, the tort system can pursue comparable results with the allocation of the residual loss on one or the other party, or the sharing of the residual loss among the parties.

2.3.5 Activity Levels and Return to Scale: "Best Scale of Activities"

An additional factor to consider when choosing the optimal allocation of non-negligent accident losses is the marginal value of activities, w_{zz}, b_{uu}. By relaxing the assumption introduced in Section 2.2 of decreasing marginal value of the parties' activities, $w_{zz}, b_{uu} < 0$, we may now consider cases characterized by increasing marginal value of the activity. The allocation of the residual loss on one or the other party will affect the parties' activity levels and their ability to optimize the scale at which their activity is carried out. All other things being equal, it will be optimal to allocate risk and liability on the party that faces decreasing marginal returns from its activity. The activity exhibiting diminishing marginal returns can, in fact, be reduced at a lower cost, given that the portion of the activity that is curtailed is characterized by lower returns.

Proposition 2.3.5. (Best Scale of Activities). *Ceteris paribus, a loss-sharing rule is desirable in equilibrium when the marginal returns from the parties' activities are decreasing. Conversely, increasing marginal returns from the activities requires an all-or-nothing approach in equilibrium.*

Proof. See Appendix 2.5. □

Proposition 2.3.5 implies that in the absence of other justifying factors, increasing marginal returns from the activity represent a necessary condition for all-or-nothing rules to be socially optimal. When the marginal returns are decreasing, the value function increases with respect to activity levels at a decreasing rate. The greater the activity level, the lower the return from an additional increase in activity level. Benefits grow at a decreasing rate, while accident risks continue to grow steadily larger. In this case, a loss-sharing rule will induce both parties to mitigate their activity levels, foregoing the less valuable final quantities of their activities. Conversely, with increasing marginal returns, increments in activity levels lead to increasingly larger gains. Thus, it may be desirable to allow at least one party (the one with the highest marginal increase) to undertake a higher activity level, with the adoption of all-or-nothing liability regime.

2.3.6 Loss-Sharing vs. Insurance: "Best Risk-Bearer"

With some exceptions (e.g., Greenwood and Ingene, 1978; Shavell, 1987; Gollier et al., 1997; Privileggi et al., 2001; Nell and Richter, 1996, 2003), the literature on tort law assumes risk-neutrality for both parties in order to isolate the effect of liability on individual incentives. Although risk-neutrality may be a reasonable approximation of preferences when corporate actors are involved or when insurance markets are readily available, risk-aversion lurks behind all remaining tort situations. The assumption of risk-neutrality in the standard tort model is justified by two compelling arguments in the literature. The first argument is that tort law should be designed to promote efficient incentives, and any attempt to use tort rules to provide an insurance function for the parties would undermine the incentive function of tort liability. The second argument is that parties involved in risky activities generally have access to well-functioning insurance markets, which reduce the need for providing insurance through tort law.

Though useful for the study of care incentives, the assumption of risk-neutrality obfuscates the analysis of other important policy dimensions that hinge upon the optimal allocation of risk. Risk preferences play an important role in individuals' choices of activity levels for risky activities. Policymakers can influence risk-taking behavior by appropriately allocating residual liability. Recent contributions to the tort literature have unveiled the limits of the conventional approach, showing that under fairly general conditions, loss-sharing and other forms of mutual insurance between faultless parties can be implemented without undermining optimal care incentives (e.g., Shavell, 1982;

Dari-Mattiacci and De Geest, 2005). Further, not all risks are insurable, and residual loss-sharing can provide a form of risk-spreading when insurance is not available. Most compellingly, unlike standard insurance, residual loss-sharing can spread the risk without corroding care incentives and creating other moral hazard problems.

As pointed out by Nell and Richter (2003), bracketing off other factors, the law should allocate risks and liability on the risk-neutral party or on the party who can more easily hedge against the risk ("best risk-bearer"). To determine which party is the best risk-bearer, the court should ascertain risk preferences and identify which party is in a better position to hedge against the risk. The best-risk-bearer criterion may run into epistemic problems as to the verifiability of risk preferences, as well as concerns of political palatability, and tastes for fairness. This may render the best-risk-bearer criterion unlikely to be used as an ad hoc basis of liability. Notwithstanding these limitations, loss-sharing could emerge as desirable legal instruments when parties have similar attitudes toward risk and invest in comparable activities (e.g., two average individuals involved in a driving accident). In this case, loss-sharing may provide a form of mutual insurance that operates when a faultless accident occurs: the risk is spread, yet preserving optimal care incentives for both parties. Further, these insights may explain some characteristics of the tort system. For example, the fact that a risk-neutral party should bear residual liability for non-negligent conduct seems a plausible explanation for the widespread use of strict liability in product liability cases (see The Product Liability Directive 85/374/EEC creating a regime of strict liability for defective products), or more generally, when victims are less likely to be able to hedge against the risk of an accident as compared to their injurers.

2.4 Analysis and Concluding Remarks

This study has pulled together several important threads of research from the law and economics literature on torts.

It is a well-established result that activity-level incentives are a function of residual liability. Shavell's (1980) activity-level theorem shows that conventional liability rules based on negligence and strict liability are unable to create optimal activity-level incentives for both parties. Negligence and strict-liability regimes apportion residual liability entirely on one or the other party. The effect of this all-or-nothing allocation is that one party (the bearer of residual liability) is fully incentivized to undertake an optimal level of activity, while the other (the non-bearer of residual liability) has no legal incentives to mitigate his or her activity level. Decoupling provides a solution by making *both* parties full bearers of residual liability. The decoupled system requires a faultless victim to remain uncompensated even if the tortfeasor paid for the full amount of the harm (Polinsky and Che, 1991): this basically implies the limited political viability of the decoupling rule on the ground of fairness, and to a general offense to the natural sense of justice. In the absence of victim compensation, it is unclear how disputes would even enter into the legal system. Without the hope of obtaining compensation for his injuries, the victim has no reason to bring suit against the tortfeasor — thereby bypassing the "perfect" liability regime entirely. For these reasons, the appeal of the decoupling solution is confined to the realm of economic theory, given its practical untenability in modern tort systems.

At this junction, the identification of a second-best apportionment of residual liability becomes critical. In addressing this policy question, this chapter examines loss-sharing rules as an alternative to conventional all-or-nothing rules, identifying the factors that determine who should bear the cost of faultless accidents. We unveiled several sub-principles embedded in Calabresi's (1970) "cheapest-cost-avoider" principle, all of which bear on the optimal allocation of residual liability. We summarize the analysis in Table 2.

The allocation of residual liability plays a fundamental role in the design of tort liability. The efficiency criteria labeled (A) through (D) in Table 2 consider the role of loss-sharing for risk-neutral parties. Our analysis shows that when parties are risk-neutral, the optimal allocation of residual loss depends on a number of factors, which include the riskiness and the value of their activities, their interaction in the production of risk, and returns to scale from the activities. Our findings explain long-standing principles of the tort system, in addition to providing ways of improving them. For example, our results show that the party who carries out the riskier activity should bear the residual liability for non-negligent conduct. This result can explain the widespread adoption of strict-liability rules in case of ultrahazardous activities, and the use of no-liability when the victim came to the nuisance or exposed herself to risk. Similarly, our analysis explains the presence of immunities or heightened standards of liability (gross negligence or intent required for liability) when socially valuable activities are

	Strict Liability	**Loss-Sharing**	**Negligence**
(A) Least Risk-Producer	Injurer's Activity Riskier	Parties' Activities Equally Risky	Victims's Activity Riskier
(B) Cheapest Activity-Avoider	Victim's Activity More Valuable	Parties' Activities Equally Valuable	Injurer's Activity More Valuable
(A)+(B) Cheapest Risk Avoider	Victim's Activity More Valuable and Less Risky	One Party' Activity More Valuable but Riskier	Injurer's Activity More Valuable and Less Risky
(C) Best Mix of Activities	Subadditive Risk	Superadditive Risk	Subadditive Risk
(D) Best Scale of Activities	Victim's Increasing Returns	Both Decreasing Returns	Injurer's Increasing Returns
(E) Best Risk-Bearer	Victim Risk-Averse	Both Risk-Averse	Injurer Risk-Averse

Table 2: *Unbundling the "Cheapest-Cost-Avoider": Optimal Allocation of Residual Liability*

involved. Yet the foregoing analysis begs the followup question: how should residual liability be divided when the factors point in different directions? For example, if the tortfeasor was the least risk-producer, but the victim was the cheapest activity-avoider, who should bear the residual loss? Most real life situations are characterized by countervailing considerations pointing in different directions. In such situations tradeoffs arise, and loss-sharing rules may ultimately emerge as a more desirable alternative than all-or-nothing approaches. Finally, while risk-neutrality may be a reasonable approximation of preferences when corporate actors are involved or when insurance markets are readily available, risk preferences remain a relevant factor in the allocation of the residual liability. With the aim of exploring a broader range of normative goals, we discussed the possible role of loss-sharing for the optimal allocation of risk between risk-averse parties. In interpreting our results, we should keep in mind that residual liability is relevant not only with respect to activity-level incentives but also for investments in non-observable precautions and research and adoption of new precautions technologies.[27] Future research could, among other things, consider how different allocations of the residual loss among non-negligent parties could promote the adoption of non-observable precautions and foster the development and use of new, safer technologies. In this regard, the next chapter deals with specific types of precaution technologies, i.e., automated technologies. Chapter 3 investigates the incentives on care and activity levels when the activity is automated, and provides a fruitful theoretical framework to study how residual liability could promote the adoption of such technologies.

It is worth stressing that the six sub-principles that we considered in this chapter are not alternatives to Calabresi's (1970) "cheapest-cost-avoider", but rather components of it. The cheapest-cost-avoider principle stands untouched as the unifying criterion that should guide the optimal allocation of the residual loss: the combined effect of the several factors involved will ultimately determine who should be the bearer of residual

[27] For a review of the literature on this point, see Dari-Mattiacci and Parisi (2006).

liability. The existence of countervailing arguments arising from our analysis should not therefore be understood as obscuring Calabresi's (1970) criterion, but rather elucidating it. Analyzing the cheapest-cost-avoider principle into sub-principles therefore gives us a handle, with which to carry out the analysis, and the aggregate effect of those factors will determine which party is the cheapest cost-avoider if one exists. A good dose of skepticism is warranted about the ability of policymakers to apply each and every sub-principle considered in this chapter, given the difficulty in measuring some of the factors involved. But these measurement problems are indeed a point of strength of loss-sharing solutions. For practical necessity, when useful information is not known to the judicial system, loss-sharing rules provide a pragmatic and possibly superior alternative to rules in which one party bears the entire accident costs. In other words, in cases where the cheapest-cost-avoider principle fails to uniquely identify one of the parties, loss-sharing may emerge as the most desirable and equitable solution. The second-best liability regime, while suboptimal by definition, may be usefully reframed as being the optimal (i.e., first-best) distribution of residual liability *with the constraint* that the total liability assigned cannot be greater than the accident loss, as when decoupling is carried out. And it is not difficult to see that in many (perhaps most) cases, such an optimum will fall somewhere between the limiting cases of negligence and strict-liability regimes, contrary to current adjudicatory practices.

As a final note, it is worth noting that this chapter has shown the conditions under which loss-sharing rules are more desirable than traditional all-or-nothing rules by focusing on primary and secondary costs of accidents, that is, on deterrence and on the optimal risk spreading and risk bearing. More specifically, Calabresi (1970) considered the total costs of accidents as divided into three categories: primary, secondary and tertiary costs. Primary costs are the accident costs which can be reduced by the prevention of accidents (deterrence). Secondary costs are the costs due to an inefficient distribution of the accident losses and can be reduced by optimally spreading the risk and the cost of accidents over society in such a way that individuals who are more able or more willing to bear the costs do bear them (optimal risk spreading and risk bearing). Tort law aims at minimizing primary and secondary accident costs as long as such minimization outweighs the increase in tertiary costs it causes (see also Visscher, 2010 on the categories of accident costs). Tertiary costs are the administrative costs of accident systems. The issue arising is that loss-sharing rules may lead to higher tertiary costs compared to all-or-nothing based rules. Among others, Rubinfeld (1987) and Dari-Mattiacci and De Geest (2005) argued that a negligence-based system with loss-sharing rules among negligence parties (namely, the rule of comparative negligence) may result in higher administrative costs because there are more cases to adjudicate and/or a higher cost per case. A similar reasoning may apply to loss-sharing rules among non-negligent parties. The comparison between loss-sharing rules and all-or-nothing rules in terms of tertiary costs warrants further investigations. If loss-sharing rules and all-or-nothing rules are equivalent with respect to care and activity levels incentives, then tertiary costs should guide the allocation of the residual loss, and all-or-nothing based rule might appear more desirable.

To conclude, Chapter 2 gives several insights for further research on the allocation of the residual liability. For example, future studies can analyze how to allocate the residual loss when one of the two parties can take precautions most cheaply (cheapest precaution taker), or can take the most effective precautions (the most effective precaution taker). Further investigations could study how to foster second-best activity levels when parties can alternatively undertake durable and non-durable precautions. Moreover, residual liability is relevant not only with respect to activity-level incentives, but also for investments in new precautions technologies. Different allocations of the residual loss among non-negligent parties could promote second-best non-observable precautions and foster the development and adoption of new precautionary technologies. This opens the perspective for further research questions on the relationship between tort law and new safer technologies. My second research question goes along this path. Chapter 3 deals with new automated technologies (e.g., driverless cars, automated drones) and analyzes their impact on the law of torts.

2.5 Appendix

Proof of Lemma 2.2.1. Let us consider a general negligence-based liability rule, where σ denotes the sharing rule between non-negligent parties, θ denotes the sharing rule between negligent parties, x^{d*} and y^{d*} are given standards of care. Under the structural-form model of our analysis, the private maximization problem of the injurer is defined as follows:

$$\max_{x,z} U_T = \begin{cases} w(z,x) - \sigma q(z,u)L(x,y) & \text{if } x \geq x^{d*} \text{ and } y \geq y^{d*} \\ w(z,x) - \theta q(z,u)L(x,y) & \text{if } x < x^{d*} \text{ and } y < y^{d*} \\ w(z,x) - q(z,u)L(x,y) & \text{if } x < x^{d*} \text{ and } y \geq y^{d*} \\ w(z,x) & \text{if } x \geq x^{d*} \text{ and } y < y^{d*} \end{cases} \tag{2.5.1}$$

Similarly, the private maximization problem for the victim is defined as follows:

$$\max_{y,u} U_V = \begin{cases} b(u,y) - (1-\sigma)q(z,u)L(x,y) & \text{if } x \geq x^{d*} \text{ and } y \geq y^{d*} \\ b(u,y) - (1-\theta)q(z,u)L(x,y) & \text{if } x < x^{d*} \text{ and } y < y^{d*} \\ b(u,y) & \text{if } x < x^{d*} \text{ and } y \geq y^{d*} \\ b(u,y) - q(z,u)L(x,y) & \text{if } x \geq x^{d*} \text{ and } y < y^{d*} \end{cases} \tag{2.5.2}$$

In order to prove that parties have incentives to comply with the due-care standard, we will proceed stepwise by showing that neither party has incentives to deviate from the due-care equilibrium by investing in suboptimal or excessive care.

Claim 1: No Under-Precautions. In equilibrium, the injurer is not able to increase his payoff by undertaking *less than due care*, i.e.,

$$w(z^*, x^{d*}) - \sigma^{**} q(z^*, u^*) L(x^{d*}, y^{d*}) > w(z,x) - q(z,u^*) L(x, y^{d*}) \tag{2.5.3}$$

for all $\forall x < x^{d*}$ and $z = z(x, y^{d*}, \sigma^{**})$.

Proof of Claim 1. Given that x^{d*}, y^{d*}, $u^* = u(x^{d*}, y^{d*}, \sigma^{**})$, and $z^* = z(x^{d*}, y^{d*}, \sigma^{**})$ maximize the social welfare function (2.2.1), we have:

$$w(z^*, x^{d*}) + b(u^*, y^{d*}) - q(z^*, u^*)L(x^{d*}, y^{d*}) = \tag{2.5.4}$$

$$= w(z(x^{d*}, y^{d*}, \sigma^{**}), x^{d*}) + b(u^*, y^{d*}) - q(z(x^{d*}, y^{d*}, \sigma^{**}), u^*)L(x^{d*}, y^{d*}) \tag{2.5.5}$$

$$> w(z(x, y^{d*}, \sigma^{**}), x) + b(u^*, y^{d*}) - q(z(x, y^{d*}, \sigma^{**}), u^*)L(x, y^{d*}) \tag{2.5.6}$$

for all $\forall x < x^{d*}$ and $z = z(x, y^{d*}, \sigma^{**})$. Since $\sigma^{**} \in [0, 1]$, we have that:

$$w(z^*, x^{d*}) - \sigma^{**}q(z^*, u^*)L(x^{d*}, y^{d*}) > w(z^*, x^{d*}) - q(z^*, u^*)L(x^{d*}, y^{d*}) \tag{2.5.7}$$

It follows that:

$$w(z^*, x^{d*}) - \sigma^{**}q(z^*, u^*)L(x^{d*}, y^{d*}) > w(z, x) - q(z, u^*)L(x, y^{d*}) \tag{2.5.8}$$

for all $\forall x < x^{d*}$ and $z = z(x, y^{d*}, \sigma^{**})$, which proves Claim 1.

Claim 2: No Over-Precautions. In equilibrium, the injurer is not able to increase his payoff by undertaking *more than due care*, i.e.,

$$w(z^*, x^{d*}) - \sigma^{**}q(z^*, u^*)L(x^{d*}, y^{d*}) > w(z, x) - \sigma^{**}q(z, u^*)L(x, y^{d*}) \tag{2.5.9}$$

$\forall x > x^{d*}$ and $z = z(x, y^{d*}, \sigma^{**})$.

Proof of Claim 2. Since $z^* = z(x^{d*}, y^{d*}, \sigma^{**})$, $u^* = u(x^{d*}, y^{d*}, \sigma^{**})$, x^{d*} and y^{d*} maximize the social welfare function (2.2.1), we have:

$$\begin{aligned} w(z^*, x^{d*}) - q(z^*, u^*)L(x^{d*}, y^{d*}) &= w(z(x^{d*}, y^{d*}, \sigma^{**}), x^{d*}) - q(z(x^{d*}, y^{d*}, \sigma^{**}), u^*)L(x^{d*}, y^{d*}) \\ &\geq w(z(x, y^{d*}, \sigma^{**}), x) - q(z(x, y^{d*}, \sigma^{**}), u^*)L(x, y^{d*}) \\ &= w(z, x) - q(z, u^*)L(x, y^{d*}) \end{aligned}$$

$\forall x > x^{d*}$ and $z = z(x, y^{d*}, \sigma^{**})$. Accordingly we have:

$$\begin{aligned} w(z^*, x^{d*}) - \sigma^{**}q(z^*, u^*)L(x^{d*}, y^{d*}) &= w(z^*, x^{d*}) - q(z^*, u^*)L(x^{d*}, y^{d*}) + (1 - \sigma^{**})q(z^*, u^*)L(x^{d*}, y^{d*}) \\ &\geq w(z, x) - q(z, u^*)L(x, y^{d*}) + (1 - \sigma^{**})q(z^*, u^*)L(x^{d*}, y^{d*}) \\ &> w(z, x) - q(z, u^*)L(x, y^{d*}) + (1 - \sigma^{**})q(z, u^*)L(x, y^{d*}) \end{aligned}$$

$\forall x > x^{d*}$ and $z = z(x, y^{d*}, \sigma^{**})$. It follows that:

$$w(z^*, x^{d*}) - \sigma^{**}q(z^*, u^*)L(x^{d*}, y^{d*}) > w(z, x) - \sigma^{**}q(z, u^*)L(x, y^{d*}) \qquad (2.5.10)$$

$\forall x > x^{d*}$ and $z = z(x, y^{d*}, \sigma^{**})$, which proves Claim 2.

We thus proved that parties' compliance with the due-care standards is not undermined under a generic fault-based liability system with loss sharing among faultless parties. It follows that activity-level incentives can be studied with a reduced-form model in which the social and private optimization problems are expressed as in (2.2.1), (2.2.4) and (2.2.5). □

Proof of Proposition 2.3.1. By considering (2.2.6) and (2.2.7), the second-order effects of marginal changes in σ on the privately optimal activity levels are given by:

$$\frac{dz^*}{d\sigma} = \frac{q_z L}{w_{zz} - \sigma q_{zz} L} \tag{2.5.11a}$$

$$\frac{du^*}{d\sigma} = -\frac{q_u L}{b_{uu} - (1-\sigma) q_{uu} L} \tag{2.5.11b}$$

By considering (2.2.6) and (2.2.7), and substituting (2.5.11), (2.2.8) becomes:

$$\frac{(1-\sigma)q_z^2}{w_{zz} - \sigma q_{zz} L} - \frac{\sigma q_u^2}{b_{uu} - (1-\sigma) q_{uu} L} = 0 \tag{2.5.12}$$

In order to isolate the riskiness of activity from the other factors, we consider symmetrical parties except for q_z and q_u. When $q_z = q_u$, (2.5.12) is satisfied for $\sigma^{**} = 1/2$. By applying the implicit function theorem, we obtain:

$$\frac{\partial \sigma^{**}}{\partial q_z} = \frac{-2(1-\sigma) q_z}{(w_{zz} - \sigma q_{zz} L)\left(\frac{q_u^2(-b_{uu}+q_{uu}L)}{(b_{uu}-(1-\sigma)q_{uu}L)^2} + \frac{q_z^2(-w_{zz}+q_{zz}L)}{(w_{zz}-\sigma q_{zz}L)^2}\right)} \tag{2.5.13}$$

which is positive by construction. Similarly,

$$\frac{\partial \sigma^{**}}{\partial q_u} = \frac{2\sigma q_u}{(b_{uu} - (1-\sigma) q_{uu} L)\left(\frac{q_u^2(-b_{uu}+q_{uu}L)}{(b_{uu}-(1-\sigma)q_{uu}L)^2} + \frac{q_z^2(-w_{zz}+q_{zz}L)}{(w_{zz}-\sigma q_{zz}L)^2}\right)} \tag{2.5.14}$$

which is negative by construction. Given that $\sigma^{**} = 1/2$ when $q_z = q_u$, (2.5.13) and (2.5.14) imply that when $q_z > q_u$, $\sigma^{**} > 1/2$; whereas when $q_z < q_u$, $\sigma^{**} < 1/2$. $\square$

Proof of Proposition 2.3.2. In order to isolate the value of activity from the other factors, we consider symmetrical parties except for w_z and b_u. By considering (2.2.6) and (2.2.7), and substituting (2.5.11), (2.2.8) becomes:

$$\frac{(1-\sigma)w_z}{\sigma(w_{zz}-\sigma q_{zz}L)} - \frac{\sigma b_u}{(1-\sigma)(b_{uu}-(1-\sigma)q_{uu}L)} = 0 \tag{2.5.15}$$

When $w_z = b_u$, (2.5.15) is satisfied for $\sigma^{**} = 1/2$. By applying the implicit function theorem, we obtain:

$$\frac{\partial\sigma^{**}}{\partial w_z} = \frac{1-\sigma}{\sigma(-w_{zz}+\sigma q_{zz}L)\left(\frac{w_z(-w_{zz}+(2-\sigma)\sigma q_{zz}L)}{\sigma^2(w_{zz}-\sigma q_{zz}L)^2} + \frac{b_u(-b_{uu}+(1-\sigma^2)q_{uu}L)}{(1-\sigma)^2(b_{uu}-(1-\sigma)q_{uu}L)^2}\right)} \tag{2.5.16}$$

which is negative by construction. Similarly,

$$\frac{\partial\sigma^{**}}{\partial b_u} = \frac{\sigma}{(1-\sigma)(-b_{uu}+(1-\sigma)q_{uu}L)\left(\frac{w_z(-w_{zz}+(2-\sigma)\sigma q_{zz}L)}{\sigma^2(w_{zz}-\sigma q_{zz}L)^2} + \frac{b_u(-b_{uu}+(1-\sigma^2)q_{uu}L)}{(1-\sigma)^2(b_{uu}-(1-\sigma)q_{uu}L)^2}\right)} \tag{2.5.17}$$

which is positive by construction. Given that $\sigma^{**} = 1/2$ when $w_z = b_u$, (2.5.16) and (2.5.17) imply that when $w_z > b_u$, $\sigma^{**} < 1/2$; whereas when $w_z < b_u$, $\sigma^{**} > 1/2$. $\square$

Proof of Proposition 2.3.3. This follows straightforwardly from the previous proofs.

In order to isolate the value and the riskiness of activity from the other factors, we consider symmetrical parties except for w_z, b_u, q_z, q_u. Let consider (2.5.12) and (2.5.15). *Ceteris paribus*, when $w_z = b_u$ and $q_z = q_u$, (2.5.12) and (2.5.15) are satisfied for $\sigma^{**} = 1/2$. From (2.5.13), (2.5.14), (2.5.16), and (2.5.17), we obtain that when $q_z < q_u$ and $w_z > b_u$, (2.5.12) and (2.5.15) are satisfied for $\sigma^{**} < 1/2$; whereas when $q_z > q_u$ and $w_z < b_u$, (2.5.12) and (2.5.15) are satisfied for $\sigma^{**} > 1/2$. When $q_z < q_u$, (2.5.12) is satisfied for $\sigma^{**} > 1/2$; when $w_z < b_u$, (2.5.15) is satisfied for $\sigma^{**} < 1/2$. When $q_z < q_u$ and $w_z < b_u$, and $\partial\sigma^{**}/\partial q_z \sim \partial\sigma^{**}/\partial w_z$, neither of the two effects prevails, thus (2.2.8) is satisfied for $\sigma^{**} = 1/2$. Similarly, when $q_z > q_u$, (2.5.12) is satisfied for $\sigma^{**} < 1/2$; when $w_z > b_u$, (2.5.15) is satisfied for $\sigma^{**} > 1/2$. When $q_z > q_u$ and $w_z > b_u$, and $\partial\sigma^{**}/\partial q_z \sim \partial\sigma^{**}/\partial w_z$, neither of the two effects prevails, thus (2.2.8) is satisfied for $\sigma^{**} = 1/2$. □

Proof of Proposition 2.3.4. When $q_{zu} \neq 0$, the second-order sufficiency condition for σ^{**} to be an interior second-best solution requires:

$$\left(\frac{\partial u^*}{\partial \sigma}\right)^2 (b_{uu} - q_{uu}L) + \left(\frac{\partial z^*}{\partial \sigma}\right)^2 (w_{zz} - q_{zz}L) + \\ - \frac{\partial^2 u^*}{\partial \sigma^2}\sigma q_u L - \frac{\partial^2 z^*}{\partial \sigma^2}(1-\sigma) q_z L - 2q_{zu}\frac{\partial u^*}{\partial \sigma}\frac{\partial z^*}{\partial \sigma} < 0 \quad (2.5.18)$$

Condition (2.5.18) is always satisfied when $q_{zu} < 0$. Condition (2.5.18) is more likely to be violated when $q_{zu} > 0$ and large, which requires by contradiction $\sigma^{**} \in \{0, 1\}$.

□

Proof of Proposition 2.3.5. The second-order sufficiency condition for σ^{**} to be an interior second-best solution requires:

$$\left(\frac{\partial u^*}{\partial \sigma}\right)^2 (b_{uu} - q_{uu}L) + \left(\frac{\partial z^*}{\partial \sigma}\right)^2 (w_{zz} - q_{zz}L) - \frac{\partial^2 u^*}{\partial \sigma^2}\sigma q_u L - \frac{\partial^2 z^*}{\partial \sigma^2}(1-\sigma)q_z L < 0 \tag{2.5.19}$$

Condition (2.5.19) is always satisfied when $w_{zz}, b_{uu} < 0$. Condition (2.5.19) is more likely to be violated when $w_{zz}, b_{uu} > 0$ and large, requiring by contradiction $\sigma^{**} \in \{0,1\}$. $\square$

3. Tort Law for Robots[28]

Since our ancient ancestors first fashioned stone tools, mankind has progressively altered his environment in greater degrees—tilling the soil, building cities, devising machines—to ease the burdens of daily life. We see these changes reflected in the history of our laws, metamorphosing to suit the social conditions they were meant to govern. From transformations in our political arrangements to advances in science and technology, nowhere is the relationship between social conditions and the law more evident than in torts. As primitive societies learned to control and exploit natural resources, they grew wealthy (Posner, 1980). And so the earliest penal codes gave way (when efficient) to a framework allowing the private payment of compensatory damages in place of punishment (Parisi, 2001). Later, as agrarian communities, consisting of sparse populations of neighbors, transformed to densely populated cities, consisting of multitudes of strangers densely packed together, the balance of harms moved from

[28] This Chapter is largely based on my paper "Tort Law for Robots," coauthored with Daniel Pi (University of Bologna, Department of Economics; University of Hamburg, Institute of Law and Economics). The authors would like to thank Carole Billiet, Emanuela Carbonara, Andrew Daughety, Luigi Alberto Franzoni, Fernando Gómez Pomar, Peter Krebs, Marco Bochatay Magnani, Alessio Maria Pacces, Francesco Parisi, Jennifer F. Reinganum, Ann-Sofie Vandenberghe, Louis T. Visscher for helpful comments and suggestions, as well as seminar audiences at the 2014 Annual Conference of the European Association of Law and Economics at the University of Aix-Marseille, the 2014 Annual Meeting of the German Law and Economics Association at University of Ghent, the 2014 EDLE spring seminar at the Rotterdam Institute of Law and Economics.

intentional to accidental. And so the attention of tort lawyers, judges, and scholars shifted toward the treatment of negligent harms. Later still, the development of industrialization and mass production introduced harms of a wholly different nature and scale (Stearns, 2012, p. 122; Hall et al., 1996, p. 116; White, 2003, p. 70). And so the law responded with procedural innovations allowing mass litigation and new rules for products liability.

Underlying these tectonic shifts in the trajectory of tort law, we see the transformation from nomadic to agrarian society, urban migration, and the industrial revolution. So much is but history, yet glancing forward to the future, we may already anticipate a fast-approaching revolutionary change, which is likely to challenge our present legal rules. Our conception of tort law has hitherto assumed the existence of two *human actors* underlying a tort—a tortfeasor and a victim. Yet this assumption grows ever more tenuous with the advancement of automated technologies. Industrialized nations are already populated by more automated devices than people. The role of humans in society today bears little resemblance to the role of humans a century ago. Today, our copyists are luminescent boxes, our launderers are whirling metal cylinders, our assembly line workers are mechanized arms, our accountants are silicon chips. Work which had for centuries occupied legions of farmers, today requires but a handful of machine operators. Yet until the last couple decades, the legal effect of all this automation has been marginal, because the *decisions* made by machines were, by and large, trivial and routine. The machine has hitherto been little more than an extension of the operator's will, incapable of forming its own judgments or acting independently. This state of affairs is rapidly changing, and as computers develop both in power and sophistication, the line between actor and tool, decision-making and routine, grows ever more difficult to discern.

Machines are now capable of driving cars, operating trains, delivering packages to homes, piloting aircraft, killing or destroying military targets, and performing surgical procedures with little or no human input. And this is only the beginning. Amidst these revolutionary changes, we are faced with the natural question—whither the law of torts?[29] For inasmuch as machines relieve us of the burden of making ever-more-complex decisions, and though errors may occur at dramatically lower rates with robots as compared to humans, accidents will nevertheless occur. And when a driverless car careens into a pedestrian, or a robot surgeon botches a procedure, what should the legal rule be? If liability is assigned, then upon whom should that liability fall: manufacturer or operator? If some variation of the negligence rule, then what should the standard of negligence be?

In this study, we offer a general theoretical approach to automated technology torts. Our aim will be to determine what legal rule is efficient in cases where injury is caused by automated technology. Unsurprisingly, we find that the ordinary rules governing negligent humans are inefficient when the actor is a machine. Under more specific conditions, we shall find that the eccentricities of the particular circumstances largely determine how we should respond, leading to several concrete albeit nuanced results.

[29]This question is not only pressing for lawyers and economists—popular media coverage of automated technology developments invariably poses the tort law question as one in urgent need of answer (Strumpf, 2011; Vanderbilt, 2013).

We divide the adoption of automated technologies into three stages. Let us call the first stage the "experimental phase." The experimental phase occurs prior to availability of the product to consumers. Since the product will not be commonly available during this time, the significance of tort law for the technology will be marginal, and we shall therefore offer no analysis of this period. Next, the "adoption stage," during which time the technology is either as safe or safer than human actors and consumers are given a choice whether to purchase manual or automated technologies. Finally, the "refinement stage," the point at which all or nearly all consumers have adopted the automated technology.

From an economic perspective, the main objective of tort law is to reduce the social cost of accidents (or equivalently, to maximize the value of risky activities). In the adoption stage, this problem reduces to two competing objectives. On the one hand, given that automated technologies will tend to be safer than human operated analogues, we will want to encourage consumers to adopt automated alternatives. At a first glance, lowering the expected cost of liability for automated technologies would seem to generate such incentives. On the other hand, we will want to encourage manufacturers to invest in making the automated technology safer. Here, increasing the expected cost of liability—forcing manufacturers to internalize the cost of accidents caused by their technology—would seem to generate the right incentives. These objectives pull us in different directions, and we shall want to find a balance, encouraging further research in automated technology safety, while also encouraging consumers to adopt the technology. We shall find that tailoring the standard of care under negligence for human operators to the level of automation will in most cases create efficient incentives. Additionally, we shall rebut an argument frequently articulated in the literature: that automated technologies open the door to creating efficient activity levels incentives. We argue that in the adoption stage at least, tort law cannot create efficient activity level incentives for all parties.

In the refinement stage, we assume that adoption of the automated technology is nearly total—in other words, most users have opted to switch from human-operated technologies to automated technologies where the two are substitutes. Here, we shall find that the legal rule which was efficient during the adoption phase, no longer creates efficient incentives. Thus, we argue that the legal rule should change when the adoption rate of the automated technology is total or nearly total. Anticipating this rule change, it is possible that manufacturers and consumers will attempt to game the system. We argue that this effect will be largely mitigated by competition and information costs.

This chapter consists of five sections. Section 3.1 summarizes the related economic and legal literature. Section 3.2 establishes an important lemma, upon which all of our main results will rely. In Section 3.3 we construct a model of unilateral accidents to account for automated products. Sections 3.4 and 3.5 examine the implications of the model for care and activity levels, respectively. And finally, Section 3.6 concludes with a summary of our results.

3.1 Related Literature

We draw from two strands in the prior literature: research on individualized vs. uniform standards of negligence, and research on liability for safety technologies. This section briefly reviews each of them.

3.1.1 Individualized vs. Uniform Standards of Negligence

Several contributions have already analyzed how care incentives change in the presence of (i) injurers for whom the cost of care and wealth differ (Rubinfeld, 1987; Arlen, 1992; Miceli and Segerson, 1995; Schmitz, 2000); (ii) victims for whom the magnitude of harm, ability, and the cost of care differ (Landes and Posner, 1987; Kaplow and Shavell, 1996; Miceli, 1997; Ganuza and Gomez, 2005), and (iii) victims and injurers that differ in their relative gain from their risky activities (Emons, 1990a,b; Emons and Sobel, 1991). In the presence of heterogeneity, the question is whether due care standards should be tailored on an individual basis or whether they should be set to some sort of "average." Several scholars have argued that the use of a reasonable person standard for a heterogeneous population is inefficient. In the presence of differing marginal rates of benefit, risk of harm, ability, and effectiveness of care, the efficient investment in precautions will differ from individual to individual, and thus a blanket standard would necessarily be inefficient (Landes and Posner, 1987; Shavell, 1987; Schwartz, 1989; Parisi, 1992; Ganuza and Gomez, 2005; Miceli, 2006; Endres and Friehe, 2011b). Yet it is contended that the application of a uniform standard is justified when it is costly to assess the individuals' precautionary care costs (Diamond, 1974; Landes and Posner, 1987; Shavell, 1987).

3.1.2 Safety Innovations, Automated Technologies and Liability Issues

Although automated technologies have not previously been investigated using formal law and economics models, categories of technology with many interesting similarities to automated technologies have been studied in the literature. In our analysis, we shall treat automated technologies as possessing two distinguishing characteristics. First, automated technologies may be regarded as "durable precautions." From the consumer's perspective, the reduction in the expected cost of accidents comes with the one-time, up-front cost of purchasing the automated good. From the manufacturer's perspective, the reduction in the expected cost of accidents comes with the one-time, up-front cost of researching (and outfitting factories to produce) the technology.

The second salient feature of automated technology safety is that it is a substitute for human precaution. When a human actor is replaced by an automated technology, not only does the automated technology reduce the expected cost of accidents, it also reduces the effectiveness of the human actor's efforts.

The durable precautions aspect of automated technologies has been extensively researched in the prior literature. Grady (1988) first defined precautions as "durable" if they are long-lasting and require a single isolated measure to be taken; and as "non-durable" if they must be taken per unit of activity. This distinction has been then applied in several models: Shavell (2008) argued the desirability of protecting durable precautions from changes in legal rules; Nussim and Tabbach (2009) revised the traditional model of unilateral accidents by introducing durable and nondurable precautions; De Mot and Depoorter (2011) focused on memory costs and showed that accidents involving nondurable technology occur more frequently than those involving durable technology; Dari-Mattiacci and Franzoni (2014) demonstrated that due-care standards should be conditioned on the impact of new technologies on expected harm. Following the definitions introduced by Grady (1988, 2009), automated technologies may be considered "compliance-saving" for their users and "compliance-using" for manufacturers. Grady (2009, pp. 213-16) introduced the distinction between technologies which are substitutes for precautionary care levels, which save on compliance effort (e.g., parking sensors, advanced navigation system), and technologies which are complements to care levels, which require high rates of nondurable precaution and thus increase compliance effort (e.g., new hemodialysis machine). By relying on a graphical analysis, Grady (2009) argued that compliance-saving technologies make negligent liability less likely and thus reduce the flow of negligence accidents. The opposite holds true with compliance-using technologies, inasmuch as they increase the opportunities for negligent behavior for the human operators. In this terminology, we may describe automation as being durable, compliance-saving technology since the range of human intervention (thus, of human error) is narrowed (Grady, 1987, 2009; De Mot and Depoorter, 2011). Moreover, if considered in a dynamic perspective, compliance-using technologies tend to evolve over time in compliance-saving technologies (Grady, 2009). Following the example by Grady (2009), at the beginning of its production, airliner technology required a constant monitoring activity in order to be effective. With the development of automated devices, airliner technology started to monitor itself and to autonomously activate the alert system in case of danger.

Beyond the analytical distinction between different types of technology, other contributions have compared the incentive effects of alternative liability systems to induce the adoption of safer technologies (Dari-Mattiacci and Franzoni, 2014). Similarly, in the environmental field there are several contributions exploring how to foster the development of new technologies to control pollution (Faure, 2009b, Section 10.4; Endres et al., 2008; Endres and Friehe, 2011a, 2012, 2013). Among others, Endres and Bertram (2006) compared the dynamic effects of strict liability and negligence rules on parties' choices to introduce efficient progress in technologies that reduce precautionary care costs; Endres and Friehe (2013) inquired what due care standards would induce technological advances in environmental contexts; Dari-Mattiacci and Franzoni (2014) proposed setting negligence standards tailored to safety technologies available to the parties. More generally, Parchomovsky and Stein (2008) discussed the adverse effect of tort law on innovation. Other scholars have considered the effect of imperfect information about a product's future risks (e.g., Wade, 1983 and Ben-Shahar, 1998 analyzed innovation incentives when useful information about the future risks of a product is not available at the time of production), and the intertwined relationship between innovation, competition and punitive damages (Baumann and Heine, 2013).

Legal scholars have also investigated the effects of liability on incentives for harms caused by automated product malfunctions in specific product areas. The general analysis of liability for software defects has received much attention in the legal literature (Levy and Bell, 1989). Some of the most widely studied software-related accidents are linked to the medical industry (Lawrence, 1987). Among others, Leveson and Turner (1993) presented a detailed accident investigation on the radiation overdoses caused by a computerized therapy machine. Medical liability for software and automated equipment defects has been among the most hotly debated issues in courts and recent tort scholarship. De Ville (1998) provided a comprehensive historical framework of the late 20th century medical malpractice litigation in the United States, highlighting the pivotal role of the development and proliferation of new medical technologies in litigation.

More recently, several contributions have questioned whether the current tort rules represent a barrier for the development and widespread diffusion of self-driving cars. Three approaches to the emergence of self-driving automobiles have been proposed: (1) that the current product liability law is still effective and adaptable to self-driven vehicles; (2) that a systematic review of the traditional tort system is needed to allow the development and production of safety technologies in a timely fashion; (3) that no prediction is possible until the new technologies will be placed on the market. As regards the first argument, Garza (2011) argued that product liability law in its present state may not need to be amended for autonomous vehicles. He claimed that, despite criticism, the expected increase in manufacturer liability will not be a "dire concern" since self-driven cars will make automobile travel safer, leading to a net decrease in the costs of liability, insurance and litigation. Similarly, Mele (2013) argued that the traditional negligence rules, together with regulatory changes, could overcome the current legal barriers. On the opposite, Calo (2010) analyzed the commercial prospects of robotics in United States, suggesting tort immunity for manufacturers in order to encourage aggressive development of this technology. He further proposes supplementing manufacturer immunity with markets for user insurance. Marchant and Lindor (2012) analyzed some legal tools that may protect manufacturers from the expected increase in liability, and discussed the possibility that manufacturers' immunity may reduce the incentives to make incremental improvements in the safety of autonomous systems. Among other, Graham (2012) supported the third argument, emphasizing the uncertainty surrounding the application of tort law to emerging technologies. He argued that the precise content of the legal rules for autonomous cars will remain unclear until these vehicles will appear on public highways.

Though relevant to our present inquiry, these considerations have focused principally on product malfunctions, where the victim is the product user. Though still at an early stage, the literature here is developing quite rapidly, and we shall have little to say about these particular issues. Rather, we will focus on cases where victims are third parties, and where the accident is not necessarily due to a design flaw or product defect. In setting our analysis we start from the premise that an accident arising from the actions of a robot actor is not, ipso facto, be the result of a design flaw or manufacturing defect. To see why this is not the case, consider chess-playing computer programs. Chess is a useful exemplar, insofar as it is an area where computers are tasked with decision-making problems, formerly the domain of human experts. The technology is now at a point where a typical home computer far outclasses the best human players, and yet there remain certain kinds of rare positions, which humans are still better at evaluating. We would not regard such “blind spots” as being design flaws or errors—and over the course of a game the slight inaccuracies that may arise from such specialized situations are unlikely to offset the overall superior play of computers.

To bring the analogy closer to our discussion, in the case of self-driving automobiles, there may arise very specialized circumstances when a human driver would avoid an accident better than a robot. Because an automated technology operates by applying general rules, there may always be special cases, which fall outside the scope of the algorithm, where a human decision-maker might perform better. For example, a human driver may know from experience that a particular stretch of road is unusually slippery, or that he should avoid a certain street that local teens use for drag racing on weekends. Yet failing to account for every special circumstance, of which there are innumerably many, should not be regarded as a design flaw or error—particularly if robots outperform humans in the vast majority of “normal” situations.

Though the economic literature addresses the elements of automated technology torts, such as durable precautions and compliance-saving technology, and though the legal literature addresses certain specialized questions about the tort implications of automated technologies, no one has yet introduced a general theoretical approach to robot torts. Our contribution may be seen as synthesizing the prior literature, along with several fresh insights, to construct a unified theoretical approach to torts where automated technologies cause injury.

3.2 Allocating Liability between Consumers and Manufacturers

It is frequently asked in the popular media, in case of injury caused by a robot, who should bear the cost of the accident—the consumer or the manufacturer?[30] In this section, we shall argue that this question is (mostly) irrelevant.

In ordinary (human) torts, we impose liability to force prospective tortfeasors to internalize the expected cost of injury. This incentivizes prospective injurers to exercise the optimal level of precautionary care when undertaking risky activities. The calculus changes completely with automated technologies—automated technologies are insensitive to "incentives," and simply execute fixed (though possibly very complex) routines. Assuming that we are past the "experimental" stage, and that robots are at least as safe or safer than human operators, we are faced with two objectives. First, to reduce the social cost of accidents, we will want manufacturers to invest in research to make automated technologies ever safer. Second, we will to want consumers to adopt the safer automated technologies.

These objectives push us in opposing directions. In order to incentivize manufacturers to invest in improving safety, it is natural to suppose that we should impose

[30]See, e.g., U.S. News and World Report, *Tesla's Next Hurdle: Who's to Blame if a Self-Driving Car Crashes?*, available at: http://www.usnews.com/news/articles/2015/04/03/teslas-next-hurdle-whos-to-blame-if-a-self-driving-car-crashes (last access on August 1, 2015).

liability on them, forcing them to internalize the cost of accidents. Yet this will increase the price of the product, reducing the rate of adoption. Likewise in the reverse direction, reducing liability will decrease prices and increase the rate of adoption, but it will also reduce the manufacturer's incentive to invest in researching further in safety. In the next sections, we will discuss how to balance these objectives, treating manufacturers and consumers of automated technologies as if they were a single entity—collectively, the "tortfeasor." Treating manufacturers and consumers/users as one party greatly simplifies our analysis. However, we must first establish that this is a valid move.

Let us begin by considering what it would look like if there were a *problem* lumping manufacturers and consumers together. Why would this be? The concern is that the efficient liability rule for automated activities, in case of an accident loss L, may be some assignment $\alpha\gamma L$, $(1-\alpha)\gamma L$, and $(1-\gamma)L$ for the manufacturer, consumer, and victim respectively, where $\gamma \in (0,1)$ is the share of liability borne by the injurers, and $\alpha \in (0,1)$ is the share of injurer liability borne by the manufacturer.

Thus, in order to prove that manufacturers and consumers may be lumped together, given a liability burden γL, we need to show that for any assignment of liability between manufacturer and consumer α, the manufacturer's and consumer's incentives remain unaffected. To see why this is the case, think of γL as an excise tax on the use of automated products. If the tax is imposed on the consumer, then that decreases the marginal benefit he derives from use of that good, and he will consume less of it. Therefore, demand for the good decreases, which in turn reduces the manufacturer's incentive to produce the good. If, on the other hand, the tax is imposed on the manufacturer, then assuming it is a competitive market, the manufacturer will increase the price of the good, effectively "passing on" the cost of the tax to the consumer, who will then consume less of the good, reducing the payoff for the manufacturer.

In either case, the effect will be identical. For any value of $\alpha \in (0,1)$, manufacturers and consumers/users will share the cost of the tax γL. Manufacturers will "pay" in the form of reduced demand, and consumers/users will "pay" either directly through liability (if liability is assigned to consumers/users) or indirectly through the increase in prices (if liability is assigned to the manufacturer).

Formally, let $a \geq 0$ denote the manufacturer's investment in automation which generally improve performance and safety of a product. The price that the manufacturer charges to the consumer for the product is denoted with $\pi(a)$, which increases as the level of product automation a increases at a decreasing rate, i.e., $\pi' > 0$, $\pi'' < 0$. Let x and w denote respectively the care level and the activity level chosen by consumers. The demand function of consumers for automated products $D(a,\pi)$ is increasing in the automation level and decreasing in the price, i.e., $D_a > 0$, $D_{aa} \leq 0$, $D_\pi < 0$, $D_{\pi\pi} \geq 0$. Let $V(a,w)$ be the benefit that consumers derive as a function of automation and activity levels, with $V_a, V_w > 0$, $V_{aa}, V_{ww} \leq 0$.

Let $p(x,a)$ denote the probability of an accident, which is decreasing in both the care level x and the automation level a, i.e., p_x, $p_a < 0$, p_{xx}, $p_{aa} \geq 0$. Let the symbol λ be the expected cost of accidents borne by the consumer and the manufacturer in case of an accident involving a third party, with $\lambda(x,a) = \gamma w\, p(x,a)\, L$. The remaining part of the expected accident loss, i.e., $\bar{\lambda}(x,a) = (1-\gamma)\, w\, p(x,a)\, L$, might fall upon the third party, which we assume cannot take any action to prevent the accident (e.g., a flying drone falling upon a pedestrian; a driverless car hitting a vehicle properly parked). We express the liability rule's incentive effects by assigning the cost of accidents to $\lambda_M = \alpha\gamma w p(x,a) L$ or $\lambda_C = (1-\alpha)\gamma w p(x,a) L$. For example, if the manufacturer is strictly liable, then $\lambda_M = \lambda(x,a)$ and $\lambda_C = 0$; if the consumer is strictly liable, then $\lambda_C = \lambda(x,a)$ and $\lambda_M = 0$. Now the private welfare functions of the manufacturer and consumer will be:

$$M(a,w,x) = D(a,\pi(a))[\pi(a) - \lambda_M(x,a)] - a \tag{3.2.1}$$

$$C(a,w,x) = V(w,a) - \pi(a) - \lambda_C(x,a) - wx \tag{3.2.2}$$

And the social welfare function will be $M + C$:

$$S = D(a,\pi(a))[V(w,a) - \lambda_(x,a) - wx] - a \tag{3.2.3}$$

Lemma 3.2.1 (Irrelevance of Liability Assignment Between Manufacturer and Consumer)**.** *Under symmetric information, given some division of the accident loss L between the victim $(1-\gamma)wpL$ and tortfeasors γwpL, the further division of liabilities between manufacturer λ_M, and the consumer/user λ_C will not affect incentives to invest in precautionary care or research and development of automated technologies, assuming there exists a competitive market.*

Proof. See Appenix 3.7. □

Thus, for any assignment of liability on the tortfeasor, it is irrelevant with respect to innovation incentives and the adoption rate of automated technologies whether the "tortfeasor" is the manufacturer or the consumer (or some admixture of the two). In either case, the incentive effects on manufacturers and consumers will be shared through pricing and demand.

Of course, in the foregoing analysis we have assumed that manufacturers and consumers are rational and that there is symmetric information.[31] We shall not attempt a rigorous treatment here, however it is worth remarking that the possible effects of cognitive biases are unclear. For example, on the one hand, if we assume that consumers are risk averse, then this suggests that liability should be assigned on manufacturers rather than consumers (distributing accident costs through pricing). If, on the other hand, we assume that consumers are optimistic, then they may think they will be "luckier" than other consumers, in which case they would rather not have the cost of accidents priced into the good, suggesting liability should be imposed on consumers. When both biases are present, it is unclear which prevails, or indeed whether they cancel each other out.

[31] Under asymmetric information, producers may know the risks of their products whereas consumers do not. In these cases, the allocation of liability between manufacturers and consumers become relevant and contingent upon the stage of technological development.

3.3 The Model: Setting the Stage

We will construct a simple unilateral care model in which the potential tortfeasor (T) influences the risk of an accident by choosing automated technology, precautionary care, and activity levels. We assume that in case of an accident, only the victim suffers a loss ($L > 0$). The injurer benefits from engaging in activity, w and may choose to expend resources on precautionary care, x or on technological automation, a.

We model automated technologies using two assumptions. First, we assume that advances in automation reduce the effectiveness of the end-user's precautions. This assumption is intuitive; for example, a self-driving car not only relieves human drivers of their responsibility to exercise care, it also renders such care efforts otiose. Let $\beta(a)$ denote the effectiveness of the injurer's precautions as a function of automated safety investments, which is decreasing in a at a constant or increasing rate ($\beta_a < 0$, $\beta_{aa} \leq 0$). Second, we assume that human precautionary care and automated technology safety are substitutes. That is, the probability p of an accident occurring decreases as a increases or x increases. Let us define the "effective care level," denoted by $f(a,x)$, as an admixture of a prospective tortfeasor's precautionary care investment and investment in automation, i.e.,

$$f(a,x) = \beta(a)x + \gamma a \tag{3.3.1}$$

where $\gamma > 1$ is a multiplier expressing the effectiveness of one unit of automation investment relative to one unit of precautionary care on the part of the individual. The multiplier γ can be interpreted as the "quality of automation," or better as the quality of a marginal unit of automation, i.e., the level of care of the manufacturer in designing and implementing additional levels of automation. In our model, γ is assumed to be exogenous since the product-user cannot influence the manufacturing quality of automation. It follows from these assumptions that advances in automation increase the effective care level, i.e., $f_a = \gamma + \beta_a x > 0$, and that in the limiting case when no investment is made in automation, our model simply reduces to the standard model, i.e., $\beta(0) = 1$ and $f(0,x) = x$.

Let $p(f)$ denote the probability of an accident, with $p_f < 0$, $p_{ff} \geq 0$. By construction, an additional marginal investment in automated safety measures reduces the probability of an accident at a decreasing rate, i.e., $p_a < 0$, $p_{aa} > 0$.

Let us now consider the rule of negligence, under which the injurer is liable if and only if he exercised less than due care (we assume that negligence standards are set at the efficient level).

3.4 Care Levels and Automation

We proceed stepwise by first analyzing the model without activity levels.[32] The social planner's objective is to define the socially optimal care level in order to minimize

[32]By maintaining Shavell's (1980; 1987) traditional assumptions under which the cost of care and expected harm are proportional to activity level, the results of this section do not change when activity levels are included in the model (see Section 3.5).

the total social costs:

$$\min_{x} S = x + a + p(f)L \tag{3.4.1}$$

The following first-order condition defines the socially optimal care standard $\bar{x}$ (omitting arguments):

$$1 + \beta\, p_f L = 0 \tag{3.4.2}$$

Likewise, the adoption of automated safety technology is socially desirable up to the point at which the marginal cost of automation equals the total marginal benefit $\bar{a}$:

$$1 + p_f\,(\beta_a x + \gamma) = 0 \tag{3.4.3}$$

By considering the relationship between the socially optimal level of care and the level of activity automation, we obtain the following results:

Proposition 3.4.1. *As automation levels increase, the efficient due care standard decreases.*

Corollary 3.4.2. *In the limiting case of fully-automated activities, the standard of due-care is zero, a Negligence regime effectively becomes a* de facto *No Liability regime.*

Proof. See Appendix 3.7. □

According to Proposition 3.4.1, the efficient negligence standard should be tailored to automation levels. The practical implementability of this proposition requires courts to set due-care standards contingent upon the level of automation, and to establish the causal relationship between autonomous devices and accidents. This result is intuitive. For example, consider a self-parking car hitting a pedestrian. Intuitively, if the accident happened while parking, courts should apply a lower due-care standard to the car operator since the system was expected to safely operate the vehicle without human input. In this case, the concept of reasonable person used to evaluate a negligent behavior should consider, among others, the specific circumstances of the case, the adopted automation level. Yet if instead the accident occurred while the human operator was driving, the fact that the vehicle is provided with automated-parking devices should not affect the definition of the due-care standard.

A higher γ means a higher effectiveness of automation devices in reducing expected accident costs, thus requiring a lower standard of care for a given automation level. The effectiveness factor γ can be also interpreted as the development status of an automated technology. Under this interpretation, for a given automation level, the standard of negligence should optimally evolve over time to keep pace with the development status of a given automated technology.

Let us now consider the private incentives to invest in care and automation under the rule of negligence. The private cost function of the injurer is given as:

$$\min_x T = \begin{cases} x + a + p(f)L & \text{if } x < \bar{x} \\ x + a & \text{if } x \geq \bar{x} \end{cases} \tag{3.4.4}$$

The following first-order condition defines the privately optimal care level x^* (omitting arguments):

$$1 + \beta p_f L = 0 \tag{3.4.5}$$

Proposition 3.4.3. *Under tailored negligence standards, injurers will always have incentives to comply with the care standard. Under non-tailored negligence standards, the privately optimal care level falls below the due-care standard as investments in automation increase. This might induce potential injurers either to exercise excessive and inefficient care, or to not adhere to the non-tailored standard, preferring to exercise privately optimal care and be considered negligent in case of an accident.*

Corollary 3.4.4. *Injurers have more incentives to invest in automation under tailored negligence standards rather than under non-tailored negligence standards.*

Proof. See Appendix 3.7. □

We should remark here on an interesting legal implication. A phenomenon which has developed gradually over the past several decades is the migration of activities from the domain of common law torts to regulatory law. Whereas automobile accidents are frequently given as exemplars of tort law, the reality is that most automobile torts are entirely determined by statutory obligations. Assuming that automated technologies will tend, at least during the developmental stage of a product, to exhibit a large degree of heterogeneity, and further assuming that it would be impractical for legislatures to enact statutory standards to cover every possible permutation of technological improvement as they are released to the public, the effect of a "tailored" negligence standard is to return tort law to its origins. Rather than assessing whether a defendant's conduct satisfied some statutorily determined standard, the tailored approach requires judges and juries to decide cases on $\gamma < pL$ or "reasonable person" bases.

Standards of negligence tailored to the level of automation underlying the injurer's activity allow us to fully exploit the potential benefits of automated technologies. Consider self-driving cars. If the standard of negligence remains unchanged with respect to automation level, the operator of a self-driving car could be held liable for an accident if he was not monitoring the road ahead while autonomous devices were driving the vehicle. In this case, the operator of a driverless car could have incentives either to always monitor the actions of automated devices, thus nullifying their function, or to not adopt safer automated devices in order to maintain a direct control on the vehicle. On the contrary, tailored standards are aligned with the purposes of automated technologies, allowing a driver to be distracted while automated devices are operating the vehicle, without be threaten by liability issues. As a consequence, under tailored due-care standards potential injurers have incentives to adopt safer, automated technologies especially for risky actions, and to prove their actual usage in courts to avoid full liability costs.

3.5 Activity Levels and Automation

In this section we introduce activity levels in the model. Let $0 \leq k(a) \leq 1$ denote the percentage of activity automation, with $k_a > 0$, $k_{aa} \leq 0$, $k(0) = 0$ (non-automated activity) and $k(a) = 1$ when $a \to +\infty$ (fully-automated activity). We define the activity level q as determined by two components: the automated component, $J = k(a)\, j(a)$ (hereafter, automated-activity level) and the non-automated component, $Z = (1 - k(a))\, z$ (hereafter, manual-activity level). For example, a vehicle can be provided with automatic parking devices and/or with autonomous cruise control, remaining otherwise non-automated. The activity level is thus given by $q = k\, j + (1 - k)\, z$. We posit that the automated-activity level increases with technological automation at an increasing or constant level, $j(0) = 0$, $j_a > 0$, $j_{aa} \geq 0$. This assumption follows by considering the benefits of adopting automated technologies on individual utilities, e.g., increased productivity, performing tasks that are beyond human capabilities, reduced operation time, improved quality and consistency of an output. For example, driverless vehicles are expected to drive more and more safely than trained professional drivers; automated drones can more safely deliver more packages than traditional courier services. Let $w(Z)$ denote the utility derived from the manual activity, and $b(J)$ the utility derived from the automated activity, which are both increasing in the activity level at a constant or decreasing rate, i.e., $w_Z > 0$, $w_{ZZ} \leq 0$, and $b_J > 0$, $b_{JJ} \leq 0$.

We otherwise follow the standard assumptions in Shavell (1987): expected accident cost are linear with respect to the activity, i.e., $L(x, a, q, \gamma) = q\, p(f)\, L$; and care costs are a multiple of the manual activity level and a constant per-unit-of-manual-activity care effort, i.e., $c(z,x) = (1-k)zx$.

The social problem with care and activity levels can be described as follows:

$$\max_{x,z,j} S = w(Z) + b(J) - (1-k)zx - a - qp(f)L \tag{3.5.1}$$

Note that when $a = 0$, the socially optimal problem in (3.5.1) turns into its standard unilateral-case formulation. The socially optimal care level remains defined as in (3.4.2). The socially optimal activity levels $\bar{z}$ and $\bar{j}$ are respectively defined as solutions of the following fist-order conditions:

$$w_Z = x + pL \tag{3.5.2}$$

$$b_J = pL \tag{3.5.3}$$

which have the standard interpretation: the socially optimal activity level is set at the point at which the benefit of a marginal increase in activity level (LHS in (3.5.2) and (3.5.3)) equals the corresponding marginal costs (RHS in (3.5.2) and (3.5.3)). For similar marginal values of activities, the automated-activity level is optimally greater than the manual-activity level since the latter implies care costs per unit-of-activity.

Negligence standards are conventionally defined solely in terms of care because of information costs: the amount and/or the frequency of an activity is usually not easily observable by courts. This claim should be revised when considering automation technologies. By automatically tracing the user's activity, these technologies can convey information to courts and juries about the user's activity level. The automated part of the activity becomes observable, thus raising the question whether it should be included in the standard of negligence. The answer lies on the trade-off between creating incentives for socially optimal automated-activity levels and creating incentives to adopt automated technologies. In order to show this trade-off, we have to introduce the private optimization problem.

If the standard of negligence is defined as in (3.4.2) only in terms of care, the privately optimal problem becomes:

$$\min_{x,z,j} T = \begin{cases} w(Z) + b(J) - (1-k)zx - a - qp(f)L & \text{if } x < \bar{x} \\ w(Z) + b(J) - (1-k)zx - a & \text{if } x \geq \bar{x} \end{cases} \tag{3.5.4}$$

In this case, the injurer will invest in the due-care level $x_1^* = \bar{x}$, but will exercise excessive activity $q_1^* > \bar{q}$, as the standard model predicts. The privately optimal manual-activity level z_1^* and automated-activity level j_1^* are respectively given by:

$$w_Z = x \tag{3.5.5}$$

$$b_J = 0 \tag{3.5.6}$$

which are greater than the socially optimal levels (3.5.2) and (3.5.3), i.e., $z_1^* > \bar{z}$, $j_1^* > \bar{j}$.

If it is possible and desirable to define the standard of negligence in terms of both care level and automated-activity levels,[33] the privately optimal problem becomes:

$$\min_{x,z,j} T = \begin{cases} w(Z)+b(J)-(1-k)zx-a-qp(f)L & \text{if } x<\bar{x} \text{ or } j>\bar{j} \\ w(Z)+b(J)-(1-k)zx-a & \text{if } x\geq\bar{x} \text{ or } j\leq\bar{j} \end{cases} \tag{3.5.7}$$

In this case, potential injurers have incentives to invest in the due-care level $x_2^* = \bar{x}$, and in a level of activity q_2^* which remains excessive with respect to the socially optimal level $\bar{q}$, but mitigated with respect to q_1^*, given the extended definition of the negligence standard.

Proposition 3.5.1. *A negligence standard tailored to the automated-activity level creates optimal incentives for automated-activity levels but dilutes the incentives to adopt and use automated devices.*

Corollary 3.5.2. *If the percentage of automated devices ought to be employed in the relevant activity is exogenously imposed, the negligence standard could be efficiently set in terms of both care and automated-activity levels. In particular, the due level of automated activity should increase with the automation level. If the percentage of automated devices ought to be employed is individually chosen by potential injurers, a negligence standard tailored to the automated-activity level potentially destroys the incentives to adopt automated technologies.*

Proof. See Appendix 3.7. □

[33] We assume that due levels of care and automated activities are set at the socially optimal levels (3.4.2) and (3.5.3)

Let us suppose that the percentage of automated devices ought to be employed in the relevant activity is fixed (e.g., through mandatory equipment regulation) or the automated technology is commonly and widespread adopted (e.g., aircraft autopilot). Following our analysis, the users of these technologies might be held liable if their automated-activity level exceed the socially optimal standard.

In the limiting case of fully automated activities, the privately optimal activity level q_2^* approaches to the socially optimal level $\bar{q}$, thus narrowing the possibility of excessive activity levels. In this situation, the non-residual bearer of expected accident costs has optimal incentives not only for care but also for activity levels. This creates an exception for Shavell's (1987) activity-level theorem, which states that no negligence-based regime can incentivize optimal activity levels for the non-bearer of residual liability, i.e., the party that does not bear the expected accident costs in the non-negligence equilibrium. This is because the non-bearer of residual liability (e.g., the injurer in a negligence-based liability regime) wants only to avoid liability by demonstrating due care, whereas the bearer of residual liability (e.g., the victim in a negligence-based liability regime) wants to minimize expected harm. Therefore, only the bearer of residual liability will have incentives to exercise the optimal activity level. This theorem should be revisited in the presence of partially ot totally automated activities. In this case, when it is possible and desirable to define the standard of negligence also in terms of automated-activity levels, also the non-residual bearer of the loss (e.g., the injurer under the rule of negligence) have incentives to mitigate excessive activity levels. The problem of the information costs related to activity levels might be therefore partially solved by mandating automated equipments for the expected riskiest parts of an activity, leaving unobservable human actions for the less risky parts.

Defining the standard of negligence also in terms of automated-activity levels might be not desirable when the automated technology is not widely adopted or mandated by regulation, that is when individuals decide autonomously whether to adopt a new automated technology. In this case, introducing an upper bound on the frequency of automated activity under penalty of liability serves as a tax on automated-activity levels. As such, this might induce individuals to prefer conducing non-automated activities, which remain unbounded from the negligence standard.

Therefore, the traceability of automated-activity levels should not implicitly lead courts to establish a negligent behavior also in terms of the observable activity level. The decision to tailor negligence standards on the basis of automated-activity levels should result from the trade-off between two policy objectives: fostering the adoption of automated technologies *versus* creating incentives to mitigate excessive automated-activity levels. Especially relevant for new automated technologies, the first objective should lead courts to define a standard of negligence only in terms of care levels, even if a percentage of the activity is *ex-post* observable. As automated devices become widely adopted or mandated by regulation, the standard of negligence could be optimally defined in terms of automated-activity levels in order to mitigate excessive levels of automated activities.

3.6 Concluding Remarks

This study amends the standard unilateral tort model by incorporating the automation level of the relevant activity. The three key insights of our analysis are: consumer demand and manufacturer's incentives to invest in automation are insensitive to the assignment of liability (between manufacturer and consumer); as investments in automation increase, individuals' care measures lose their effectiveness in preventing an accident; and the automated part of the activity becomes traceable, thus observable ex-post. These observations allow the traditional analysis of liability law to keep pace with modern, automated technologies as, for example, in the case of automated drones and self-driving cars.

Our results show that the definition of the negligence standard is determinant for the injurers' choices to adopt safer automated technologies and to mitigate excessive automated-activity levels. Figure 3.1 summarizes the results of our analysis by showing how the standard of negligence should evolve with the automation level of the activity on the basis of the policy objective.

In our first result, we argue that the standard of care should be tailored to the automation level of the activity (left-panel in Figure 3.1). More specifically, the efficient standard of care should decrease with increasing automation. Therefore, when considering only care levels, a negligence regime gradually transforms into a no-liability rule as the activity tends toward full automation. Tailoring care standards to activity automation serves as a policy instrument to induce individuals to adopt new automated

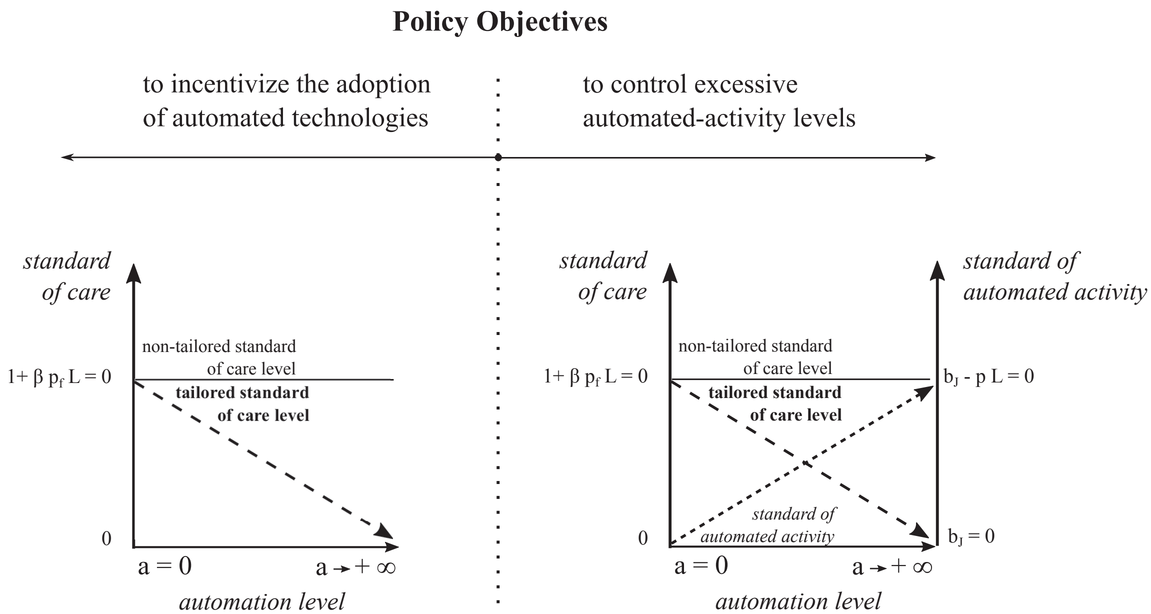


Figure 3.1: *Tailoring Standards to Automated Activities*

technologies, given that the cost of adopting new technologies generates higher private payoffs than exercise per-unit-of-activity care. A uniform care standard (as conventionally defined) would destroy adoption incentives.

The second result of our analysis focuses on activity levels. By automatically tracing users' activities, automated technologies can convey information to courts about users' activity levels. However, the traceability of automated-activity levels should not implicitly lead courts to set a corresponding negligence standard. The decision to tailor negligence standards to both care and activity levels should result from the trade-off between two policy objectives: to incentivize the adoption of automated technologies, and to control excessive automated-activity levels (right-panel in Figure 3.1). These objectives lead to opposite conclusions. Considering activity levels in the negligence standard could create optimal incentives, but would potentially destroy the incentives to adopt automated technologies in the first place. For this reason, in order to encourage the adoption of new automated devices, it would be optimal to tailor negligence standards only to care levels, even if automated-activity levels become ex-post observable by courts. For widely used automated technologies or mandated automated equipments, it is socially optimal to include automated-activity levels into a tailored negligence standards, which increases with activity automation.

Scientific and technological advances in the automation sector open new horizons in the domain of liability law, and have the potential to change our legal definition of negligence. This study is a first attempt to update traditional accident models by considering the automation level of activities. The main message of our analysis is that a revised definition of the standard of negligence makes the traditional fault-based liability regimes effective and adaptable to new automated technologies. Tailored-to-automation standards of negligence create optimal incentives to invest in safer devices and represent an optimal solution for liability law to keep pace with recent innovations in technological automation. As with other policy instruments, such as mandatory equipment or insurance discounts, tailored-to-automation negligence standards could create optimal incentives for the timely production and widespread adoption of new safer technologies, leading to an efficient reduction in the social cost of accidents.

3.7 Appendix

Proof of Lemma 3.2.1. In order to prove Lemma 3.2.1, we have to show that, assuming competitive pricing, (i) consumer demand is insensitive to the assignment of liability rule between manufacturer and consumer; and (ii) the manufacturer's incentives to invest in automated safety are insensitive to the assignment of liability between manufacturer and consumer. The mechanism at work here is intuitive: the assignment of liability may be regarded as a tax, which is shared between the manufacturer and the consumer. Let us first consider consumers' demand function, and assume that consumers are heterogeneous in their purchasing decision.

Let $\Gamma = \{c_0, c_1, \ldots, c_n\}$ be the set of potential consumers. We first define two subsets of Γ: the set of consumers who will purchase the good in case liability is assigned to the consumer $\Gamma^{\text{CL}} \subseteq \Gamma$, and the set of consumers who will purchase the good in case liability is assigned to the manufacturer $\Gamma^{\text{ML}} \subseteq \Gamma$. Let $W^{\text{CL}}(c_x) = C_x^{\text{CL}}$ denote the welfare function C_x^{CL} of consumer c_x when liability is assigned to the consumer, and let $W^{\text{ML}}(c_x) = C_x^{\text{ML}}$ denote the welfare function C_x^{ML} of consumer c_x when liability is assigned to the manufacturer.

Let b be the cardinality of the set of consumers who will purchase the good, and let Π be the profit margin of the manufacturer (it is plausible that competition effects will drive prices near or equal to the cost of production, though this proof does not rely on this assumption). Thus, we assume that $\pi(a)^{\text{CL}}(a) = \frac{a}{b} + \Pi$ both when there is no liability, and when liability is assigned to the consumer. Correspondingly, we assume

$\pi(a)^{\text{ML}} = \frac{a}{b} + \Pi + wpL$ when liability is assigned to the manufacturer.

It follows that $D(a, \pi^{\text{CL}}) = |\Gamma^{\text{CL}}|$ and $D(a, \pi^{\text{ML}}) = |\Gamma^{\text{ML}}|$. Thus, if $\Gamma^{\text{CL}} = \Gamma^{\text{ML}}$, then it can be shown that demand is unaffected by the assignment of liability between the manufacturer and consumer.

Rational consumers will only buy the good if the net benefit they receive from the good is greater than their opportunity cost O. Thus, for any individual x, if $W^{\phi}(c_x) > O_x$ then the potential consumer purchases the good. We may therefore define $\Gamma^{\text{CL}} = \{c_x | W^{\text{CL}}(c_x) > O_x\}$ and $\Gamma^{\text{ML}} = \{c_x | W^{\text{ML}}(c_x) > O_x\}$.

Suppose for *reductio* that $(\exists c_x)(c_x \in \Gamma^{\text{CL}}) \wedge \neg(c_x \in \Gamma^{\text{ML}})$. Then it must be the case that:

$$C_x^{\text{CL}} = V_x(w_x, a) - \left(\frac{a}{b} + \Pi\right) - w_x pL - w_x x_x > O_x \tag{3.7.1}$$

$$C_x^{\text{ML}} = V_x(w_x, a) - \left(\frac{a}{b} + \Pi + w_x pL\right) - w_x x_x < O_x \tag{3.7.2}$$

But we can see that $C_x^{\text{CL}} = C_x^{\text{ML}}$, so it cannot be the case that $C_x^{\text{CL}} > O_x$ while $C_x^{\text{ML}} < O_x$, lest we get the inconsistency $C_x^{\text{CL}} > C_x^{\text{CL}}$. The same reasoning applies in the mirror case where $(\exists c_x)\neg(c_x \in \Gamma^{\text{CL}}) \wedge (c_x \in \Gamma^{\text{ML}})$ with inequality signs reversed. Therefore, it follows that $(\forall c_x)(c_x \in \Gamma^{\text{CL}}) \Leftrightarrow (c_x \in \Gamma^{\text{ML}})$. Thus, the demand function D is unaffected by the assignment of liability between manufacturer and consumer.

Let us show now that the manufacturers' incentives to invest in automated safety are insensitive to the assignment of liability (between manufacturer and consumer).

Under consumer liability, the manufacturer welfare function is given by:

$$\begin{aligned} M^{\mathrm{CL}} &= D(a,\pi(a))\pi^{\mathrm{CL}}(a) - a = \\ &= D(a,\pi)\left(\frac{a}{b}+\Pi\right) - a \end{aligned} \tag{3.7.3}$$

Under manufacturer liability, the manufacturer welfare function is given by:

$$\begin{aligned} M^{\mathrm{ML}} &= D(a,\pi)\left(\pi^{\mathrm{ML}}(a) - \lambda\right) - a = \\ &= D(a,\pi(a))\left(\left(\frac{a}{b}+\Pi+\lambda\right) - \lambda\right) - a \end{aligned} \tag{3.7.4}$$

Since in equilibrium $D(e,p^{\mathrm{CL}}) = D(e,p^{\mathrm{ML}})$, and because Equation (3.7.3) is equal to Equation (3.7.4), it follows that the manufacturer's welfare function is insensitive to changes in liability allocation (between consumer and manufacturer). Consequently, the optimal automated investments a^* will not change depending on the assignment of λ.

□

Proof of Proposition 3.4.1 and of Corollary 3.4.2. Given the first-order condition (3.4.2), by applying the implicit function theorem, we obtain:

$$\bar{x}_a = -\frac{\beta_a p_f L + \beta p_{ff} f_a L}{\beta^2 p_{ff} L} \tag{3.7.5}$$

which is negative by construction. By considering (3.4.2), as $a \to \infty$, the marginal benefits of undertaking care, i.e., $\beta\, p_f\, L$, go to zero given β_a, $p_a < 0$, thus implying $\bar{x}_{a \to \infty} = 0$.

For illustrative purpose, let us suppose $x, a \in [0,4]$, $\gamma \in (1,4]$, $\beta = \sqrt{(1 - {}^{a^2}/_{16})}$, and $p(f) = 1 - \sqrt{f}/4$. In this case, the due-care standard can be defined explicitly as:

$$\bar{x}^{\dagger} = \frac{\left(16 - a^2\right) L^2 - 1024 a\gamma}{256\sqrt{(16 - a^2)}} \tag{3.7.6}$$

In the limiting cases, when $a = 0$ (non-automated activity), $\bar{x_0}^{\dagger} = {}^{L^2}/_{64}$; when $a = 4$ (fully-automated activity), given $a \in [0,4]$, $\bar{x_1}^{\dagger}$ goes to zero. The derivative of $\bar{x}^{\dagger}$ with respect to a is:

$$\bar{x}_a^{\dagger} = -\frac{16384\gamma + a\left(16 - a^2\right) L^2}{256\left(16 - a^2\right)^{3/2}} \tag{3.7.7}$$

which is negative given $a \in [0,4]$. □

Proof of Proposition 3.4.3 and of Corollary 3.4.4. The proof of the compliance with due-care standards follows directly from the comparison between (3.4.2) and (3.4.5). When the standard of negligence does not incorporate the automation level, the social minimization problem is traditionally modeled as:

$$\min_{x} \tilde{S} = x + p(x)L \tag{3.7.8}$$

which leads to the socially optimal care level $\tilde{x}$ defined as:

$$1 + p_x L = 0 \tag{3.7.9}$$

It follows that $\tilde{x} = \bar{x}$ when $a = 0$ in (3.4.1), and that $\bar{x}$ becomes lower than $\tilde{x}$ as a increases given that $\bar{x}$ decreases in a. The private optimization problem is defined as in (3.4.4). Given that the privately optimal care level (3.4.5) is decreasing in a, it follows that $x^* = \tilde{x}$ only when $a = 0$, and $x^* < \tilde{x}$ as a increases. If injurers exercise at least due care, they will maximize $x + a$ s.t. $x \geq \tilde{x}$. If injurers decide to not adhere to the standard and to exercise privately optimal care, they will maximize $x + a + p(f)L$ s.t. $x < \tilde{x}$. Exercising privately optimal care is preferred over exercising due care iff

$$\tilde{x} - x^* > p(f^*)L \tag{3.7.10}$$

where $f^* = \beta(a)x^* + \gamma a$.

A non-negligent injurer has more incentives to invest in technological automation under tailored standards rather than under non-tailored standards when $\bar{x} + a < \tilde{x} + a$, which is always verified for $a > 0$. $\square$

Proof of Proposition 3.5.1 and of Corollary 3.5.2. Let us suppose that the percentage of automated devices ought to be employed is exogenously fixed. In this case, the standard of negligence could be optimally set also in terms of automated-activity levels. In particular, the socially optimal level of automated activity j^* should increase with the automation level. Given the firs-order condition (3.5.3), by applying the implicit function theorem we obtain:

$$J_a = \frac{p_a L}{b_{JJ}} \tag{3.7.11}$$

which is positive since $p_a < 0$ and $b_{JJ} \leq 0$. Let us now suppose that the percentage of automated devices ought to be employed is individually chosen by potential tortfeasors. If the negligence standard is not tailored to automated-activity levels, the privately optimal automated-activity level j^* is given by (3.5.6). If the negligence standard is tailored to automated-activity levels, potential injurers should undertake a level of automated activity lower or equal to $\bar{j}$ defined by (3.5.3) in order to avoid expected liability costs. Given that $\bar{j} > j^*$, potential injurers have more incentives to adopt and use automated technologies when the negligence standard is not tailored to automated-activity levels.

$\square$

4. Presumption of Negligence[34]

The incentives to adopt new technologies and to invest in precautionary measures are affected not only by the allocation of primary and residual liability, as shown in Chapters 2 and 3, but also by the allocation of the burden of proof. This chapter is about the incentive effects of legal presumptions in tort setting. We analyze three interrelated effects of legal presumptions in a tort setting: (1) incentives to invest in evidence technology; (2) incentives to invest in care-type precautions; and (3) incentives to mitigate excessive activity levels.

Evidence technology affects both the viability and the effectiveness of evidence rules. This chapter considers the impact that new evidence technology could have on the range of available choices of legal presumptions. The law of evidence generally places the burden of producing evidence on plaintiffs, *de facto* creating a rebuttable presumption of non-negligence in favor of the defendant (Talley, 2013). In the event

[34]This chapter is largely based on my paper "Presumption of Negligence," *Minnesota Legal Studies Research Paper No. 14-23*, coauthored with Barbara Luppi (University of Modena and Reggio Emilia, Department of Business and Economics; University of St. Thomas School of Law) and Francesco Parisi (University of Minnesota, Law School; University of Bologna, Department of Economics). The paper has been submitted for publication. The authors would like to thank Omri Ben-Shahar, Emanuela Carbonara, Luigi Alberto Franzoni, Jonathan Klick, Marie Obidzinski, Louis T. Visscher for helpful comments and suggestions, as well as seminar audiences at the 2015 Joint Seminar 'The Future of Law and Economics' at Université Paris (X) Ouest Nanterre La Défense and the 2015 Annual Meeting of the American Law and Economics Association at Columbia Law School.

of a negligent accident, this means that a victim is generally faced with the burden of producing evidence about the negligent behavior of his tortfeasor, as a condition for establishing liability and obtaining compensation.

As recently pointed out by Sanchirico (2008), the victim bears the burden of proof, even though the content of the required evidence relates to the activity of the defendant. The tortfeasor may have better information about his own conduct than the victim does, but it is nevertheless up to the victim to prove the facts supporting his claim. This basic characteristic of the law of evidence rests on a variety of rationales, often embedded in notions of procedural economy (Hay, 1997; Hay and Spier, 1997; Shin, 1998), reliability of evidence in the face of risk of contamination (Sanchirico, 2004), and more general concerns of procedural justice.[35] In terms of procedural economy, putting the burden on the plaintiff allows unsupported legal claims to be weeded out and dismissed by summary judgment, hence reducing the defendant's costly involvement in full-fledged litigation. From a pragmatic point of view, the burden of proof initially falls on the plaintiff because the salient facts that are needed to establish liability are facts that the defendant would have no incentive to disclose to the court, and that defendants might actually have an opportunity to fabricate or tamper with (Sanchirico, 2004). Defendants are better informed, but this does not mean that they are in a better position to reveal accurate and reliable information to the court, given that their private information could be prejudicially used by their plaintiffs (Sanchirico, 2008).

[35] Recent theoretical law and economics literature has investigated the theoretical quagmire of the burden of proof (Hay and Spier, 1997; Daugherty and Reinganum, 2000; Sanchirico, 2008; Bernardo et al., 2000; Talley, 2013). Hay and Spier (1997) derive the optimal choice of burden of proof on the basis of parties' relative cost of discovery.

Evidence law could trigger the revelation of private information by the defendant, creating legal presumptions that shift the burden of proof to the defendant. However, these presumptions are only exceptionally used. For example, a presumption of negligence on the defendant can arise from the circumstances of an accident, when the accident could not have normally happened without somebody's negligence. See for example *Byrne v. Boadle*.[36] This presumption of negligence, known as the *res ipsa loquitur* doctrine ("the thing speaks for itself") constitutes an exception to the general presumption of non-negligence. Similarly, *prima facie* cases and affirmative defenses shift the burden to the other party, based on considerations of procedural economy and on the greater probability that a certain event is true under the circumstances (Hay and Spier, 1997).

Recent scientific and technological innovations have substantially changed the landscape of evidence practice. Think, as examples, of the new frontiers of evidence made possible by genetic testing, computer recording of data, digital timestamping, third-party electronic archival systems, black-box technology, body cameras and traffic surveillance cameras, satellite imaging, Snapshot® technology, and GPS tracking devices. However good or bad these devices may be in terms of usefulness and invasiveness of our private lives, these new technologies are transforming the routine information protocols of our times. Scientific and technological advances will continue to provide new opportunities and to open new horizons in the domain of legal discovery.

[36] 2 H. & C. 722, 159 Eng. Rep. 299 (Exch. 1863).

This chapter explores the extent to which a broader range of legal presumptions could be used thanks to the availability of new evidentiary technology. The adoption of different legal presumptions could shift the burden of producing evidence to the more informed party and, in turn, afford new degrees of freedom in the choice of substantive rules.[37] Legal presumptions play three interrelated roles in tort law. First, presumptions allocate the burden of proof between the parties. The new frontiers of evidentiary technology would allow policymakers to exploit the comparative advantage of the parties in accessing and revealing relevant information, therefore limiting the invasion of privacy by adversarial discovery. Second, legal presumptions could affect the parties' incentives with respect to both care and activity levels. Third, legal presumptions could become instruments for increasing the robustness of legal incentives in the face of evidentiary problems.

The chapter is structured as follows. Section 4.1 reviews the existing literature on burden of proof and identifies omitted issues. We identify and build upon two separate bodies of literature, looking at the interaction between evidentiary and substantive rules in tort law. In Section 4.2, we introduce the concept of "best discovery-bearer" and contrast it to the "cheapest evidence-producer" criterion elaborated in the current literature. We consider the role of these criteria as guiding principles for the allocation of burdens of proof and choice of legal presumptions. We show that a properly

[37]The presumption of non-negligence (and the resulting allocation of the burden of proof on the plaintiff) has historically affected the choice of substantive tort rules. Tort law could have developed very differently. Prominent legal theorists, ranging from seventeenth century Hugo Grotius to modern-time Guido Calabresi, have hypothesized radically different tort rules, but their ideas could find no incarnation in real-life legal systems, because of the obstacles posed by the law evidence, among other reasons. For a historical survey, see Parisi and Fon (2005).

defined legal presumption would reallocate and possibly minimize the effects of evidentiary uncertainty on the parties' incentives in tort law. Section 4.3 discusses how legal presumptions can be selectively used to shift the burden of proof to the party who has readier access to the relevant information and whose care level and activity level incentives are more critical for accident costs. Section 4.4 concludes with some policy considerations.

4.1 Legal Presumptions and Evidence Technology

Legal presumptions play three interrelated roles in tort law, affecting the viability and effectiveness of substantive rules, the parties' incentives with respect to their activities, and the options available to lawmakers in regulating accident law. Our analysis departs from much of the previous literature on burden of proof, that (with the exception of Sanchirico, 2008) explained the choice of presumptions on the bases of parties' relative cost of discovery, truth-finding by the court, and litigation incentives.

4.1.1 The "Cheapest Evidence-Producer" Criterion in the Existing Literature

The law and practice of evidence places an important weight on the role of legal presumptions. In an attempt to systematize the various contributions on burden of proof in tort law, Talley (2013) distinguishes several interrelated concepts related to the notion of burden of proof. These concepts are operationally interdependent, but theoretically distinct: “burden of persuasion,” “burden of production,” and “presumptions.” Specifically, the concept of burden of persuasion defines how evidence should be weighted and how much probative evidence should be offered to convince the fact finders. Standards of proofs are those that specify the criteria for applying the burden of persuasion. Talley (2013) differentiates the burden of production from the burden of persuasion. This concept refers to the rules that identify which party is required to “produce” the evidence (or, as Adler and Michael, 1931, p. 63 called it, the “burden of coming forward with the evidence”). Legal presumptions are instead rules that operate as a default, allocating the initial burden of production. An unfavorable presumption shifts the burden of producing contrary evidence on the other party.

There are relatively few authoritative attempts in the literature of law and economics that address the selection of legal presumptions. Several contributions tackle the question from the point of view of procedural economy, starting from the premise that the burden of proof should be placed onto the party who can provide reliable evidence at the lowest cost. An important formulation of this principle, which we shall refer to as the “cheapest evidence-producer” principle, can be found in Hay (1997) and Hay and Spier (1997), who include the goal of accuracy in fact-finding, and reach the conclusion that the burden of proof should best be placed onto the party with access to relevant information as a way to minimize the cost of obtaining accurate results. A subsequent incarnation of the “cheapest evidence-producer” principle can be found in Shin (1998) who formulated the argument that the burden of proof should be placed onto the party with better knowledge regarding the relevant facts. The cheapest evidence-producer criterion that emerges from this literature fundamentally captures various considerations of procedural economy.

The idea that the burden of proof should be allocated to the party with better access to relevant facts and information was later criticized by Sanchirico (2004) and Sanchirico (2008). Sanchirico questions why the many arguments of procedural economy put forth in the current literature are not reflected in current evidence law. He identifies a possible flaw in the premise that the party with better access to relevant information is also the party who can most reliably and cheaply provide the information to the court. Sanchirico suggests that this premise is the Achilles' heel of the existing literature, pointing to the many problems related to reliable disclosure and evidence tampering that arise when evidence is offered by those who have direct access to it. He provides an alternative explanation for existing evidence law, suggesting that the burden of proof is generally allocated to influence the primary-activity behavior of the parties, rather than as a way to minimize the cost of truth-finding and adjudication.

In the following, we wish to push this analysis further by looking at the dynamic effects of shifting the burden of proof to defendants. We contrast the results of our analysis to those put forth in the existing literature, recasting the cheapest-evidence criterion in light of the parties' incentives to invest in evidence technologies.

4.1.2 The Negative-Proof Fallacy

A primary argument used to explain the reason for placing the burden of proof on the plaintiff is the fact that a burden placed onto the defendant would often entail a negative proof. From a logical point of view, this objection is quite important and, if accepted, would *de facto* undermine the significance of any further analysis. Therefore, we shall tackle this preemptive objection at the outset of our analysis.

According to the logical foundations of the law of proof, the burden of proof should be placed onto the person making an assertion or claim. The procedural laws of evidence are viewed as embracing this basic principle, when they allocate the burden of proof to plaintiffs. According to the conventional argument, shifting the burden of proof to the person denying an assertion or a claim would constitute a logical fallacy, as it would presume the claim is true unless otherwise disproven. In the field of negligence law, the victim bears the burden of proof of the elements necessary to establish the tortfeasor's liability. Shifting the burden of proving the non-existence of those elements to the alleged tortfeasor (e.g., by creating a presumption of negligence) would reproduce the same logical fallacy, since the person resisting a tort claim would face the formidable burden of providing a negative proof to show a lack of negligence on his part.

The logical premise of this argument is that negations often involve universal negatives, while affirmations do not. The formidable proof of a universal negative is what ancient Romans called *probatio diabolica* (literally, "devil's proof"), to signify its heinous difficulty. Consider as an example the allegation of a fact: "Defendant signed a contract promising X." A signed document and a few additional pieces of corroborating evidence would suffice to establish the probability of such an assertion. On the contrary, the negative claim by defendant "I have never signed a contract promising X" would entail the proof of a universal negative, ultimately requiring the examination of a potentially infinite amount of evidence by the fact-finder.

Despite the logical soundness of this argument, we suggest that the negative-proof fallacy is too often invoked in the law of evidence, when the factual premises of the argument do not hold. Consider the case of a negligence tort. Proving the non-negligence of the tortfeasor at the time of the accident (or, for this matter, proving that any other element of the tort is not present) does not entail the proof of a universal negative. Proving non-negligence amounts to proving due diligence. While at times it may be easier for a plaintiff to prove the negligence of his defendant, at other times it may be easier for a defendant to prove his or her own diligence. Neither type of proof requires supernatural abilities, and nothing dictates that, in this case, the burden of proof should necessarily be placed onto the plaintiff making an assertion or claim (Adler and Michael, 1931).[38] The choice of optimal allocation of the burden of proof in these cases should hinge upon a test of comparative advantage in the access to relevant information. The party who has such comparative advantage is referred to as the "cheapest evidence-producer." This test of comparative advantage may be informed by some general assumptions and guiding rules of thumb. For example, when the standard of due care entails the undertaking of a large number of actions, proof of diligence can be more burdensome than proof of negligence. Proof of negligence could be satisfacto-

[38] In the early 1930s, Columbia law professor Jerome Michael and Chicago philosopher and law professor Mortimer Adler pointed out the inapplicability of these philosophical constructs to the legal notions of burden of proof and choice of legal presumptions when they observed that: "The principles of logic do not place upon either party any burden of proving the propositions which they have respectively alleged. The principles of logic are concerned only with the validity and the structure of the processes by which proof and disproof are accomplished." (Adler and Michael, 1931, p. 60).

rily obtained by showing that any one of the required actions had not been undertaken. Proof of diligence would instead require evidence that each of the due precautionary actions was undertaken. In the limiting case in which an infinite number of actions need to be undertaken to satisfy due care, a negative proof of non-negligence would become impossible.

In real life, activities that provide grounds for liability vary in complexity and access to factual information. Consider the other limiting case, in which the tortfeasor's negligence allegedly took the form of a given action or omission, say speeding above the posted limit. The proof by the plaintiff that speeding occurred is the equivalent of the proof by the defendant that speeding did not occur. Logic can say nothing about which of the two parties should bear the burden of proof in this case. If one party has better access to that factual information and can reliably supply new evidence to the fact-finder (i.e., if the conditions identified by Sanchirico, 2004 hold), the optimal allocation of the burden of proof should then be on that party. For example, if the defendant can more easily prove the speed at which he was driving, thanks to the adoption of GPS tracking or blackbox technology, the burden should optimally be imposed on him.

4.1.3 Legal Presumptions and the Adoption of Evidence Technology

If, as it seems, there is nothing fundamentally necessary about placing the burden of proof on plaintiffs, the next logical question becomes that of identifying the factors that should drive the optimal allocation of the burden of proof.

New technology is substantially increasing the amount of information that can be acquired and preserved, with far-reaching applications in the fields of legal evidence and discovery. Scientific and technological innovations play a dual role in evidence and discovery. Some technologies can give the fact-finder insights, allowing her to look back and gather information about past events, while others record and preserve present information for future uses. We shall refer to the first group as "investigative technologies" and to the second group as "fact-keeping technologies."

1. *Investigative Technologies:* The characteristic feature of investigative technologies is that they can be employed *ex post*, even though no such technology was available at the time of the event. Consider, for example, evidence obtained through genetic testing. Similar to a lie detector, genetic testing can shed light on past events. This technology need not be adopted by the parties at the time of the original event, but can be deployed when a need for discovery arises at a later time.

2. *Fact-Keeping Technologies:* Other technologies collect information about present events and preserve it for future investigations. This category encompasses two subgroups. The first is technology that can be adopted by third parties, including local governmental authorities, such as traffic surveillance cameras and satellite imaging, capable of documenting facts and events that occurred within their range. We shall refer to them as "*public* fact-keeping technologies." The second involves technologies that individuals and firms can privately adopt. These are instruments that are tailored to a specific set of applications, determined by their user. Examples that fall

within this category include adoption of body cameras by police officers, installation of black-box technology on vessels, installation of Snapshot® technologies on cars, use of digital timestamp certification methods, use of electronic archival systems managed and certified by third-parties in digital communities, and various applications of GPS technology. We shall refer to them as "*private* fact-keeping technologies."

Both investigative and fact-keeping technologies have changed the relative cost of providing evidence. As will be discussed in Section 4.2, the change in the cost of accessing information and delivering it to the fact-finder may affect the institutional choice of the optimal burden of proof in evidence law under the "cheapest evidence-producer" criterion.

It is important to point out that the incentives to adopt private fact-keeping technologies are endogenously determined by evidence law. For example, evidence law could make private fact-keeping technologies discoverable (i.e., usable in court against the party that adopted the technology). Under existing presumption rules, this could reduce or, in some cases, entirely undermine the incentives of the parties to adopt such technology. Think of a Snapshot® device that could be installed on a car. If the information gathered by this device could be used in court against the driver in the event of an accident (or a traffic violation, for this matter), the likelihood that anyone might want to adopt such technology would diminish, notwithstanding the possible incentives offered by insurance companies. Insurance companies themselves would be less prone to promote the adoption of this technology, knowing that it might increase the expected liability of its insureds, thereby creating an increased exposure for the insurance company itself. These problems may be theoretically corrected by adopting regulations that mandate the adoption of evidentiary technology (e.g., use of black-box technology on aircrafts, or body cameras on police officers). However, it would be hard to make a case that the entire spectrum of evidence technology could be effectively promoted through legal mandates and regulation. Further, the use of evidentiary technology would only represent one necessary but not sufficient condition for the effectiveness of these technologies in the field of evidence. Information collected by private fact-keeping technologies needs to be made discoverable in litigation for it to be a useful source of evidence and this may hit against individual liberties, constraints of privacy and procedural economy.

Therefore we suggest that legal presumptions may play a more effective and less intrusive role in creating incentives for the voluntary adoption of private fact-keeping technologies, while giving a greater protection of freedom of choice and privacy protection for the parties. Evidence technology could only benefit and never hurt the party who is faced with the burden of proof and persuasion. For example, a party who knows that he may be faced with the burden of proving his diligent behavior would develop an interest in adopting such technology. Legal presumptions should therefore be tailored to incentivize the efficient adoption of evidence technology. In the following, we consider the effects of legal presumptions on other incentives in tort law.

4.2 Legal Presumptions and the Robustness of Incentives: The "Best Discovery-Bearer"

Negligence law provides a good example of the interdependence between evidence rules and substantive rules in the creation of incentives. Negligence liability imposes liability on a tortfeasor when his behavior was negligent. Under normal circumstances, the tortfeasor probably knows better than his victim if he engaged in negligent behavior. Yet, when the plaintiff bears the burden of proof the court requires the less informed victim to prove the negligence of his tortfeasor. Consider a hypothetical shifting of the burden of proof. An example could be a legal rule that imposes liability on the tortfeasor, unless the tortfeasor can prove his diligent behavior. This rule would shift both the liability and the burden of proof to the more informed party, imposing on the tortfeasor the burden of proving his diligence as a condition for avoiding liability.

As pointed out by Hay and Spier (1997), in a hypothetical world of error-free adjudication, the choice between two twin alternatives would leave care incentives unchanged. However, when adjudication errors are introduced, presumptions could affect the final allocation of liability and, in turn, affect the parties' care and activity level incentives. We shall begin our analysis by considering the effects of a legal presumption of non-negligence on the tortfeasor under a simple negligence regime. Suppose that with probability α_{NN}, the plaintiff fails to prove the tortfeasor's negligence and the tortfeasor avoids liability notwithstanding his negligence. The objective function of the tortfeasor in a simple negligence regime can be described by the following function:

$$T_{NN} = \begin{cases} u_T - (1-\alpha_{NN}) p_L\, j & \text{if } k_T = 0 \\ u_T - k_T & \text{if } k_T = \bar{k}_T \end{cases} \tag{4.2.1}$$

where u_T is the benefit from the activity; p_L is the probability of an accident when the defendant does not take care; k_T is the cost of taking care; $\bar{k}_T$ is the cost of taking socially optimal care; and j is the victim's loss from an accident. In our setting, parties' choice in the primary activity is binary: no care or socially optimal care. The standard analysis shows that the negligence rule induces efficient care because it creates a discontinuity in the injurer's expected costs. However, if plaintiff fails to satisfy his burden of proof of negligence with probability α_{NN}, the discontinuity may be reduced and the two branches overlap. Intuitively, the tortfeasor will choose to undertake precautions as long as the cost of exerting care k_T is lower than the expected cost of no care, equal to $(1-\alpha_{NN})p_L\, j$. However, tortfeasors facing high care costs relative to expected loss imposed in case of accident may find it optimal not to invest in care. Evidence problems may thus dilute a tortfeasor's care incentives. The defendant will undertake optimal care only if the probability that the plaintiff will be able to prove the defendant's negligence is sufficiently high. As probatory difficulties for the plaintiff increase, $\alpha_{NN} \to 1$, a simple negligence rule gradually degenerates into a no liability rule as shown in Figure 4.1, undermining the prospective defendant's care incentives. A change in the legal presumption could mitigate this problem.

Let us consider a presumption of negligence on the tortfeasor under simple negligence: if the tortfeasor fails to produce evidence of his own diligence he bears full liability. Let β_N denote the probability of a failed proof of diligence. The objective function of the tortfeasor in a simple negligence regime can be described as follows:

$$T_N = \begin{cases} u_T - p_L\, j & \text{if } k_T = 0 \\ u_T - \beta_N\, p_H\, j - p_H\, c_T - k_T & \text{if } k_T = \bar{k}_T \end{cases} \tag{4.2.2}$$

where p_H is the probability of accident if the defendant undertakes care, and c_T is the tortfeasor's cost of presenting evidence. Evidentiary problems change the relative price of negligent versus non-negligent behavior. A burden placed onto the defendant reduces the wedge between the payoffs in cases of diligent versus non-diligent behavior. Unlike what is observed in (4.2.1) for $\alpha_{NN} \to 1$, the negligence rule in (4.2.2) degenerates into a strict liability rule as probatory difficulties for the defendant increases, $\beta_N \to 1$, as shown in Figure 4.1.

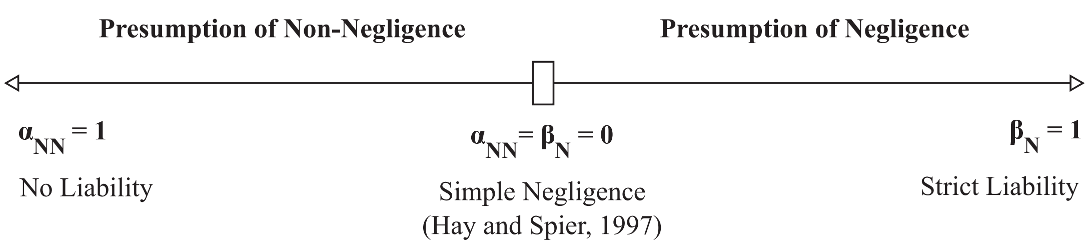


Figure 4.1: *Non-Equivalence of Presumptions under Simple Negligence*

A similar analysis applies to other liability regimes. Consider for example a regime of strict liability with contributory negligence. If there is a presumption of contributory non-negligence on the victim, her objective function can be described as follows:

$$V_{NCN} = \begin{cases} u_V - (1-\beta_{NCN})p_L\, j & \text{if } k_V = 0 \\ u_V - k_V & \text{if } k_V = \bar{k}_V \end{cases} \tag{4.2.3}$$

where u_V is the benefit from the activity; p_L is the probability of an accident when the plaintiff does not take care; k_V is the cost of taking care; $\bar{k}_V$ is the cost of taking socially optimal care; and β_{NCN} is the probability that the tortfeasor fails to prove the victim's contributory negligence. If there is a presumption of contributory negligence on the plaintiff, the objective function is defined as:

$$V_{CN} = \begin{cases} u_V - p_L\, j & \text{if } k_V = 0 \\ u_V - \alpha_{CN}\, p_H\, j - p_H\, c_V - k_V & \text{if } k_V = \bar{k}_V \end{cases} \tag{4.2.4}$$

where p_H is the probability of accident if the plaintiff takes care; c_V is the victim's cost of presenting evidence; and α_{CN} is the probability that the victim fails to produce evidence of his contributory non-negligence. As probatory difficulties increase, the rule of strict liability with contributory negligence degenerates as shown in Figure 4.2.

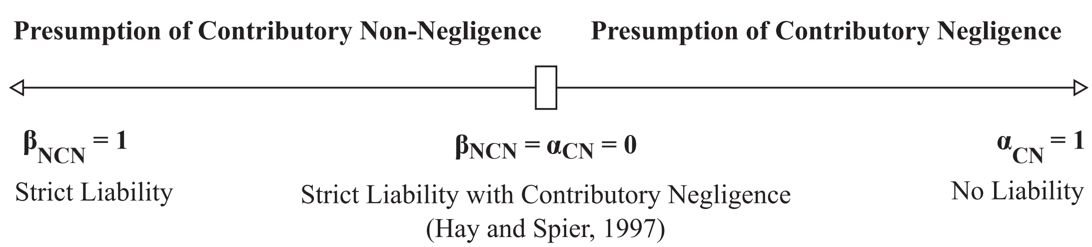


Figure 4.2: *Non-Equivalence of Presumptions under Strict Liability with Contributory Negligence*

Our result reconciles the analysis with Hay and Spier (1997) when the burden of proof does not affect care incentives.

Proposition 4.2.1. *In the presence of evidentiary problems, legal presumptions should be created against the best discovery-bearer.*

Corollary 4.2.2. *In the absence of evidentiary problems, the analysis of Hay and Spier (1997) holds.*

Proof. See Appendix 4.5. □

In a world of perfect adjudication, legal presumptions can be created to minimize truth-finding costs without altering incentives. As shown by Figures 4.1 and 4.2, without discovery errors, legal presumptions have no effects on the allocation of liability and on the parties' incentives. A rule of simple negligence remains unchanged when a presumption of negligence is introduced against the tortfeasor. Likewise, a rule of strict liability with a defense of contributory negligence remains unchanged when a presumption of contributory negligence is introduced against the victim. This confirms the results of Hay and Spier (1997).

However, presumptions affect parties' incentives when discovery is imperfect, and the robustness of liability rules is affected by the choice of presumptions. More specifically, the use of a presumption of negligence against the tortfeasor increases the robustness of negligence-based rules, while the use of a presumption of contributory negligence against the victim increases the robustness of strict-liability rules. This can be explained by observing that, in a negligence regime, discovery problems may undermine the tortfeasor's care incentives. When primary liability is allocated on the basis of negligence, incentives for a tortfeasor's care can be effectively preserved with the adoption of a presumption of negligence. For similar reasons, discovery problems may undermine the victim's care incentives. When primary liability is allocated on the basis of strict liability, incentives for a victim's care can be effectively preserved with the adoption of a presumption of contributory negligence.

In both cases, legal presumptions can be used to minimize the impact of imperfect discovery on the parties' incentives. A selective use of presumptions can thus increase the robustness of liability rules in the face of large evidentiary problems. Most notably, in a world of imperfect adjudication, legal presumptions can be used to strengthen incentives in the face of evidentiary problems. This often implies shifting the burden to the individual whose precautions are more inelastic relative to discovery error.

As a final remark, it is important to consider the effects of alternative legal presumptions on administrative costs. As pointed out in Chapter 2, under fault-based regimes prospective injurers and potential victims will both behave non-negligently, and therefore a large number of the accidents will occur despite the due diligence of the individuals involved. In these cases, a presumption of non-negligence might be more cost-effective than a presumption of negligence since it would substantially reduce the number of litigated cases with beneficial savings in the administrative costs of the tort system. Further research could investigate the interrelated effects between alternative non-negligence regimes (i.e., "all-or-nothing based rules" vs. loss-sharing rules) and legal presumptions in terms of administrative costs and incentives to enter litigation.

4.3 Burden of Proof as an Activity Level Tax

Gathering information about the parties' levels of care is among the most problematic elements of discovery in tort litigation. Litigants generally have better information about their own behavior at the time of the accident, but are generally required to prove the negligent behavior of their counterparts. The less informed party has to extract information from the more informed party through discovery. For example, tortfeasors have information about their own behavior, but the burden of proof rests on their victims. Likewise, for defenses such as contributory or comparative negligence, the tortfeasor has to prove the victim's negligence, even though the tortfeasor has less access to such information.

In the preceding sections, we have critically examined the rationales for the traditional allocation of the burden of proof. We have evidenced the limits of the cheapest-evidence-producer rationale in light of the parties' asymmetric opportunities to invest in new evidentiary technology, and the effect of presumptions on care incentives. We have shown that legal presumptions can be selectively used to shift the burden of proof to the party who can more effectively adopt evidence technology and whose incentives are more critical for accident costs.

In the following, we will observe that legal presumptions can serve an additional objective and become a policy instrument for mitigating excessive activity levels.

A presumption that shifts the burden of proof from one party to the other will increase the expected cost of the activity for such party. In the event of an accident, the burdened party will have to incur the cost of producing evidence and will bear the accident loss when he fails to produce the necessary evidence. Neutral as this burden may appear, it has important effects. More specifically, a presumption that shifts the burden of proof to the defendant increases the cost of both negligent and non-negligent accidents. The cost associated with the burden of proof is qualitatively similar to a tax imposed on the activity that generates the risk. This tax will reduce the level of activity for the party facing the burden of proof. This reduction in activity level can be desirable or undesirable, depending on which party bears the residual liability in the specific case. This warrants further elaboration. As per Shavell's activity level theorem, no negligence based regime can incentivize optimal activity levels for both parties (Shavell, 1980).[39] This is because the party who does not bear the residual liability is only concerned about avoiding liability by undertaking due care, and does not internalize the additional cost of non-negligent accidents. Conversely, the bearer of residual liability wants to avoid harm altogether and will be incentivized to undertake both optimal care and optimal activity level. In Chapter 2, I have shown that under certain circumstances, loss-sharing rules among non-negligent parties are more desirable than traditional all-or-nothing based rules in terms of activity-level incentives. Under loss-

[39] An ideal remedy in tort law should instead incentivize optimal precautionary care levels and optimal activity levels for both parties. Shavell (1980) showed that this ideal is not achievable under negligence-based regimes, because only the bearer of residual liability will have incentives to mitigate its activity level. This proposition has become known in the law and economics literature as "Shavell's activity level theorem."

sharing based rules, parties share the loss on the basis of the relevant characteristics of their activities, e.g., riskiness and value.

When considering the traditional all-or-nothing based rule, the cost imposed by the burden of proof can therefore do either of two things: depress the activity levels of the residual bearer below the social optimum, *or* mitigate the excessive activity levels of the non residual bearer. For example, when the victim is already the residual bearer (e.g., under a negligence regime), imposing the burden of proof on the victim may depress her activity level below the optimal point. In a negligence regime, a presumption of negligence would therefore be desirable, by shifting the evidentiary burden to the party who is not already burdened by the residual liability, thereby inducing both parties to mitigate excessive activity levels. According to our analysis, *ceteris paribus*, the burden of proof should be allocated to the party who does not face the residual loss in the event of a non-negligent accident, i.e., presumptions should be placed in favor of the residual bearer. The intuition behind this argument is that the burden of proof imposes a tax on the activity which can alternatively *distort* the efficient incentives of the residual bearer, or *mitigate* the inefficiently high activity levels of the party who does not bear the residual loss. The burden of proof can thus be used as an activity level tax with a legal presumption in favor of the party burdened with the accident loss when both parties acted diligently. Practically, this would entail creating a presumption in favor of the plaintiff when the dispute arises under negligence regimes (i.e., simple negligence, negligence with contributory negligence, or negligence with comparative negligence), and a presumption in favor of the defendant when the dispute arises under strict liability regimes (i.e., strict liability with contributory negligence, or strict liability with comparative negligence). In this manner, legal presumptions could be used to create a partial decoupling, ultimately bringing the activity levels of both parties closer to socially optimal levels.

4.4 Concluding Remarks

This study developed a simple tort model to analyze the effects of legal presumptions on parties' incentives to invest in evidence technology, and on parties' incentives to invest in care and activity levels. Care and activity level incentives are not symmetrically affected by shifts in the burden of proof. Tort incentives react differently to changes in legal presumptions, and this provides a new normative criterion for the choice of evidence regimes. We identified three factors that affect the optimal allocation of the burden of proof. The first factor considers the effects of legal presumptions on the incentives to invest in evidence-production technology, such as Snapshot® technologies and body cameras on police officers. The second factor is based on the idea that legal presumptions shift the effects of evidentiary uncertainty from one party to the other and, by doing so, legal presumptions affect care level incentives. According to our analysis, legal presumptions should be chosen to ensure that evidentiary problems do not corrode the parties' primary care incentives. Therefore, the burden should be shifted onto the party whose precautions are more inelastic relative to discovery errors. The third factor is based on the idea that legal presumptions shift the cost associated with evidence problems from one party to the other. These costs are equivalent to an activity level tax, and legal presumptions can be created in favor of the residual bearer, such that activity level incentives can move closer to optimality.

4.5 Appendix

Proof of Proposition 4.2.1 and of Corollary 4.2.2. Here we develop the claim advanced in Section 4.2 of Chapter 4. Consider first the effects of legal presumptions under a regime of simple negligence. Following Hay and Spier (1997), let us introduce the notation:

$k_T =$ tortfeasor's cost of taking care

$e =$ tortfeasor's cost of technology adoption

$p_H =$ probability of accident if the tortfeasor takes care

$p_L =$ probability of accident if the tortfeasor does not take care

$j =$ victim's losses from an accident

$c_T =$ tortfeasor's cost of presenting evidence when evidentiary technology is not adopted

$c_V =$ victim's cost of presenting evidence when evidentiary technology is not adopted

$c_{Te} =$ tortfeasor's cost of presenting evidence when evidentiary technology is adopted

We assume that taking care is efficient, i.e.,

$$k_T < (p_L - p_H)\, j \tag{4.5.1}$$

and that

$$c_{Te} < c_T < j \tag{4.5.2}$$

Consider the case with no adjudication errors (Hay and Spier, 1997). Suppose that there is a presumption of non-negligence on the tortfeasor, i.e., the plaintiff has the burden of proof. The defendant's cost of acting negligently is $p_L\, j$. The defendant will take care if

$$k_T < p_L\, j \tag{4.5.3}$$

which is true anytime (4.5.1) holds. Suppose now there is a presumption of negligence on the tortfeasor, i.e., the tortfeasor has the burden of proof. If he is negligent, he will be held liable; if he is careful, he will not be held liable. Depending on whether evidentiary technologies have been adopted, the defendant will take care if

$$k_T + p_H\, c_T < p_L\, j \tag{4.5.4}$$

$$k_T + p_H\, c_{Te} + e < p_L\, j \tag{4.5.5}$$

Condition (4.5.4) is true anytime (4.5.1) and (4.5.2) hold. When (4.5.4) holds, the tortfeasor finds it convenient to adopt technology when the LHS in (4.5.5) is lower than the LHS in (4.5.4), i.e.,

$$e < p_H\,(c_T - c_{Te}) \tag{4.5.6}$$

Let us introduce adjudication errors. Suppose that there is a presumption of non-negligence on the tortfeasor, i.e., the plaintiff has the burden of proof. Let $0 \leq \alpha_{NN} \leq 1$ be the probability that the plaintiff fails to prove the tortfeasor's negligence. The defendant will take care if

$$k_T < (1 - \alpha_{NN})\,p_L\,j \tag{4.5.7}$$

which is true when $\alpha_{NN} \leq {}^{p_H}/_{p_L}$ and (4.5.1) holds. Suppose now that there is a presumption of negligence on the tortfeasor. Let $0 \leq \beta_N \leq 1$ be the probability that the defendant fails in proving his non-negligence. For simplicity, we assume $\beta_N = 0$ when the defendant adopts evidentiary technologies. Depending on whether evidentiary technologies have been adopted, the defendant will take care if

$$k_T + \beta_N\,p_H\,j + p_H\,c_T < p_L\,j \tag{4.5.8}$$

$$k_T + p_H\,c_{Te} + e < p_L\,j \tag{4.5.9}$$

Condition (4.5.8) is true when $\beta_N \leq 1 - {}^{c_T}/_{j}$, (4.5.1), and (4.5.2) holds. When (4.5.8) holds, the defendant finds convenient to adopt technology when the LHS in (4.5.9) is lower than the LHS in (4.5.8), i.e.,

$$e < p_H \, (c_T - c_{Te}) + \beta_N \, p_H \, j \tag{4.5.10}$$

which is more easily satisfied than (4.5.6) when $\beta_N > 0$.

By comparing (4.5.7) with (4.5.8), the defendant has more incentives to undertake due care under a presumption of negligence rather than under a presumption of non-negligence when the following condition is satisfied:

$$p_H \, c_T < (\alpha_{NN} \, p_L - \beta_N \, p_H) \; j \tag{4.5.11}$$

where $\alpha_{NN} \, p_L \, j$ is the plaintiff's expected share of the loss which remains uncompensated notwithstanding the defendant's negligence, and $\beta_N p_H \, j$ is the plaintiff's expected share of the loss notwithstanding his non-negligence. Similarly, by comparing (4.5.7) with (4.5.9) the defendant adopting evidentiary technologies has more incentives to undertake due care under a presumption of negligence rather than under a presumption of non-negligence when the following condition is satisfied:

$$p_H \, c_{Te} < \alpha_{NN} \, p_L \, j - e \tag{4.5.12}$$

Given (4.5.2) and (4.5.10), (4.5.12) is more easily satisfied than (4.5.11).

Let us now consider the condition under which it is socially efficient to shift the burden of proof when evidentiary technology is not adopted. Suppose $\alpha_{NN} > {}^{p_H}/_{p_L}$ and $\beta_N \leq 1 - {}^{c_T}/_{j}$. under a presumption of non-negligence the tortfeasor will be negligent, while under a presumption of negligence the tortfeasor will be diligent. Under a presumption of non-negligence, the total cost faced by society is $p_L\, j + p_L\, c_V$. Under a presumption of negligence, the total cost borne by society is $p_H\, j + p_H\, c_T + k_T$. It is socially efficient to shift from a presumption of non-negligence to a presumption of negligence when $p_L\, j + p_L\, c_V > p_H\, j + p_H\, c_T + k_T$. This condition can be rewritten as

$$k_T < (p_L - p_H)\, j + p_L\, c_V - p_H\, c_T \tag{4.5.13}$$

By symmetry, a similar analysis applies to victims' care incentives under a regime of strict liability with contributory negligence.

□

5. Measuring Social Preferences in Accident Prevention[40]

The preceding chapters have considered prospective tortfeasor and his victim as risk-neutral individuals, free from any type of prosocial behavioral bias and moral sentiment. However, the literatures on prosocial preferences and emphatic behavior show that people care about the others' well-being and feel empathy for the others' pain (Cooper and Kagel, 2009; Crockett et al., 2014). Morality and prosocial moral sentiments which involve sacrificing some of personal benefits to prevent others' losses (Blair, 1995), might influence care choices in an accident context. Do individuals adopt a different precautionary behavior depending upon their role in an accident?

[40]This chapter is dedicated to the memory of Theodore Eisenberg, for inspiring conversations at the very outset of this research during his visits at the University of Bologna and at the University of Hamburg in 2013. The title of this manuscript echoes the title of Crockett et al.'s (2014) paper, that is, "Harm to others outweighs harm to self in moral decision making," with the aim to highlight the opposite experimental results achieved under the different contexts analyzed in the two studies. The author is extremely grateful to Stefania Bortolotti and Francesco Parisi for the guidance and the encouragement on this project from the beginning. The first session of the experiment was conducted in January 2015 at the University of Bologna, Department of Economics, thanks to the cooperation of Emanuela Carbonara. The second session was conducted in February 2015 at the University of Modena and Reggio Emilia, Department of Economics, thanks to the cooperation of Barbara Luppi. The author is very grateful for their suggestions and support. The author would also like to thank Maria Bigoni, Marco Casari, Christoph Engel, Michael G. Faure, Alessio M. Pacces, Enrico Santarelli, Ann-Sofie Vandenberghe, Louis T. Visscher for their helpful comments, and the participants in the SONIC meetings at the University of Bologna and in the 2013 EDLE winter seminar in Erasmus University Rotterdam.

How does feeling responsible for someone else's losses affect precautionary behavior? How people evaluate the cost of their monetary losses compared to the cost of the others' monetary losses, and how this evaluation changes with contexts, is still under investigation. This chapter addresses this issue by testing whether individuals care more about their own safety rather than the others' safety. Recent contributions on prosocial behavior showed that an agent who bears the responsibility for someone else's welfare, will behave in a more pro-social manner ("responsibility-alleviation principle"; Charness, 2000; Charness and Jackson, 2009). This study analyzes private care choices in a risky context, showing that individuals care more about losses to self rather than losses toward others, and spend more resources to avoid suffering a loss (even under perfect compensation) rather than causing a loss to others (and pay compensation). These results contribute to better define the boundaries of prosocial behaviors and ultimately suggest a new non-neutral context —substantially different from the standard neutral contexts used to test altruistic behaviors— to study social interactions in risky situations.

This chapter adds to the growing literature in psychology, neuroscience, behavioral and experimental economics which questioned prosocial behaviors from different perspectives. Smith (1759) first hypothesized that individuals naturally tend towards moral behaviors.[41] This moral sentiment, embedded in social norms that discourage

[41] "There is no commonly honest man who does not more dread the inward disgrace of such an action [. . .], that for one man to deprive another unjustly of any thing, or unjustly to promote his own advantage by the loss or disadvantage of another, is more contrary to nature, than death, than poverty, than pain, than all the misfortunes which can affect him, either in his body, or in his external circumstances." (Smith, 1759, III.3.8).

harming others (Fehr and Fischbacher, 2004; Henrich et al., 2010), leads people to dislike bad outcomes, especially when those harm others, and to evaluate the others' pain as higher than own pain. A second prediction on moral behaviors emerges from studies investigating how people behave in economic exchanges. It has been shown that individuals are willing to donate shares of their endowment to anonymous strangers (Engel, 2011), and to cooperate in social dilemmas (Rand et al., 2012). When related to their own monetary outcome, however, people care much less about the others' monetary outcome (Henrich et al., 2010). This predicts that individuals care about the others' losses, but far less than their own losses. The literature on other-regarding preferences shows that individuals care for the well-being of others, and that human behavior inevitably deviates from utility maximization (Eckel and Grossman, 1996; Fehr and Fischbacher, 2004; Fehr and Schmidt, 2006). Experimental studies provided evidence that people are willing to help others even at a personal cost, independently of the characteristics or the intentions of the recipients (unconditional or pure altruism, sometimes called interdependent utility; Fong, 2007). A third hypothesis on moral behaviors comes from studies on empathic experiences which enable individuals to understand others' feelings like sadness, happiness, and also pain. These contributions predict that individuals evaluate others' pain similarly to how they evaluate their own pain — assuming that the cost of pain for others is similar to the cost of pain for oneself (Masserman et al., 1964; Batson et al., 1981; Singer et al., 2004). Recently, Crockett et al. (2014) quantified how individuals evaluate the costs of pain to themselves and others in a neutral social context, and they found a "hyperaltruistic" valuation of others' pain relative to own pain.

The aim of this chapter is to test whether individuals care more, or at least as much as, about the others' safety rather than their own safety in an accident context. Are people more averse in injuring someone or in being injured? In order to address this question, I performed a paper-based experimental study that relies upon the theoretical predictions of the economic analysis of accident law.

The standard models of accident law assume that individual utility depends only on own material payoff, without involving concerns for others (Shavell, 1980, 1987). By relying on this presupposition, the economic analysis of tort law predicts that potential injurers and prospective victims make identical precautionary choices under different but mirrored liability rules —e.g., the no liability rule is the mirror image of the strict liability rule. More specifically, an injurer under the no liability rule has theoretically no incentives to take precautions to avoid an accident, since that rule does not require him to compensate the victim for the accident loss. The same zero-care choice is expected from a victim under the strict liability rule. This rule requires the injurer to always compensate the victim for accident loss. Knowing that, in case of an accident, she will always receive compensation, the victim's optimal strategy is not to invest in precautionary measures. Similarly, a victim under the no liability rule and an injurer under the strict liability rule would choose to undertake the socially optimal care level to minimize the total expected accident costs. Given these symmetrical choices under different liability rules, strict liability is considered the mirror image of no liability (Cooter and Ulen, 2007, pp. 228-229; Miceli, 1997). Other liability rules are considered as mirror images. The strict liability rule with contributory negligence defense can be interpreted as a "negligence rule for victims" (Miceli, 1997; Müeller-Langer and Schäfer, 2009). Under the simple negligence rule, the tortfeasor will be held liable for injury losses only if he was negligent, i.e., if he exerted a level of care lower than the level specified by courts, namely the due-care standard. Under strict liability with contributory negligence, the victim receives compensation in all cases except if she behaved negligently. The Nash equilibrium is thus derived exactly as in the case of simple negligence, with injurer and victim reversed. For simplicity of experimental design and interpretation of results, in my analysis I will test only two mirrored liability rules, namely the no liability rule and the strict liability rule.

The theoretical properties of mirrored liability rules hold true under perfect compensation if individuals are "role indifferent," i.e., if they invest the same level of precautionary measures regardless of them being the cause of a monetary loss to others or the victim of a monetary loss. In the example above, parties are expected to expend the same amount of precautions either if they are victims under the no liability rule or if they are injurers under the strict liability rule. The question arising is whether individual behavior is *actually* "role indifferent" or rather "role averse": people might have a different perception of risk and damages depending upon their being victims or injurers of an accident, and their being perfectly insured or not. The motivation for the research arises from the literature on social preferences. Indeed, the experimental literature on other-regarding behavior already showed that people care about others' well-being even at a personal cost and independently from the characteristics or the intentions of the recipients, and tend to evaluate the others' losses as higher than their own losses (Eckel and Grossman, 1996; Fehr and Fischbacher, 2004; Fehr and Schmidt, 2006; Fong, 2007; Cooper and Kagel, 2009; Engel, 2011). Several contributions that analyzed individual behavior in economic exchanges showed that subjects are willing to donate shares of their endowment to anonymous strangers (Engel, 2011), and to cooperate in social dilemmas (Rand et al., 2012). However, people care much less about others' monetary outcome when related to their own (Henrich et al., 2010). This predicts that individuals care about others' losses, but far less than their own. Recent studies on empathic behavior showed that individuals evaluate others' pain similarly to how they evaluate their own — assuming that the cost of pain for others is similar to the cost of pain for oneself (Masserman et al., 1964; Batson et al., 1981; Singer et al., 2004). Recently, Crockett et al. (2014) quantified how individuals evaluate the costs of pain for themselves and others in a neutral social context, and they found a "hyperaltruistic" valuation of others' pain relative to their own.

The experimental design presented here aims at quantifying whether and how much individuals care about own safety compared to how much they care about the others' safety. Three are the main results of this study. First, injurers have to fully compensate victims for accident damages, victims invest in care about as much as injurers. This is the most interesting and surprising result: even if perfectly insured, victims nevertheless spend resources to prevent the accident. This result can be interpreted as another instance of social preferences: when victims are perfectly insured and injurers cannot take actions to prevent the accident, victims see it as unfair to make potential injurers loose money with a high probability and spend resources to avoid unjust liability to injurers. On the contrary, when not entitled to receive compensation for accident losses, victims invest significantly more than injurers. In the “Injurer, No Liability” case, around 40% of injurers spend nothing to avoid causing an accident. Given that injurers in this case are essentially playing a risky dictator game, this result can be seen as coherent with the standard finding in dictator games, in which, on average, around 36% of all dictators give nothing to the recipient (Engel, 2011). However, injurers in the “Injurer, No Liability” case nonetheless undertake on average more than 60% of victims’ investments in the “Victim, No Liability” case. This can be interpreted as another instance of social preferences: given that victims cannot take actions to avoid the accident, injurers feel it as unfair to make victims suffering unjust and uncompensated losses. The second result shows that, on average, subjects spend more resources in the role of victims rather than in the role of injurers. This signals that individuals do care about others’ safety but less than their own safety. The third result shows that subjects spend more in care measures in the presence of expected liability costs. This is coherent with the theoretical and experimental literature on liability law (Shavell, 1980; Kornhauser and Schotter, 1990, 1992; Angelova et al., 2013), and suggests that individuals are more willing to prevent losses to self rather than losses to others (Engel, 2011; Henrich et al., 2010). So, for example, injurers are more averse in paying compensation of damages rather than in causing uncompensated damages. Similarly, potential victims undertook less precautions when they were expected to receive full compensation and more precautions when they were expected to bear the full accident costs.

These observations, which deserves further investigations, offer a new perspective on prosocial behaviors in risky situations and have important implications for the economic analysis of accident law. This research ultimately tests the predictive power of tort models, and allows to setup more realistic economic models of liability law.

This chapter proceeds as follows. Section 5.1 provides an extended review of the related literature. Section 5.2 presents the experimental model, and formally derives the hypotheses. Section 5.3 describes the experimental design, and Section 5.4 discusses the results. Section 5.5 concludes with a condensed summary of the implication of the results for the literatures on prosocial behaviors and for the economic analysis of accident law.

5.1 Extended Literature Review

This study relies on and contributes to three streams of literature: the economic literature on other-regarding preferences; the neuroscientific literature on empathic behavior, and the economic literature on liability law. In the following, I review each of these briefly.

5.1.1 Experimental Literature on Other-Regarding Preferences

A considerable amount of experimental research investigated other-regarding behaviors from different angles and perspectives. Among others, Fehr and Fischbacher

(2003) and Cooper and Kagel (2009) provide an extensive survey of the experimental results on other-regarding preferences; Rotemberg (2006) discusses the literature on reciprocity and altruism in the workplace; and Camerer (2003, pp.43-100) shows a general broad overview of experiments to test unselfish behavior.

Experiments on altruism are primarily based on ultimatum or dictator games, and focused on two classes of fairness: unconditional altruism or strong reciprocity, and reciprocal or reputation-based altruism (Fehr and Fischbacher, 2003; Fong, 2007). The difference between them is intuitive. Strong reciprocators bear the cost of being altruist even in the absence of reputation or other private gain from their acts, whereas reciprocal altruists take actions only if they have long term interests. Results are various and, beyond the acknowledgment that people tend to not choose the most selfish outcome, the conditions which are likely to motivate altruistic behaviors appear to be hardly identifiable. This is partly due to two influential factors: the context-independent design generally implemented, and the effect of experimental design characteristics.

As regard the first factor, the lack of a realistic social context in ultimatum and dictator games has been addressed by varying the characteristics of the recipients and the information available to the donors. Among others, Eckel and Grossman (1996) compared the donations to anonymous student subjects with the donations to an established charity within double-anonymous experiments. They found that dictators in the charity experiment are less likely to keep the entire amount in the envelope (only 27% of dictators keep $10 when the recipient is a charity institution, in contrast to 63% when the recipient is an anonymous student subject), and that, on average, subjects in the charity treatment donated 31% of their payoffs, in contrast to 10.6% donated by dictators with anonymous recipients. Similarly, Fong (2007) analyzed the outcomes from a charity game involving real-life welfare recipients. The author found a strong evidence of both conditional and unconditional altruism, and that self-reported unconditional altruists highly react to the worthiness of the recipient.

Also the characteristics of the experimental design may influence subjects' choices, causing a misleading expectations of generosity outside the lab. Bardsley (2008) argued that subjects' donations in dictator games may be an "artefact of experimentation" (i.e., participants perceive that the game is about giving, and react to this sort of experimental demand), and proved that dictators are less willing to give money when a taking option is available. The evidence that a simple manipulation of the experimental design influences individuals' behaviors is proved also by List (2007), who explored a dictator game with variations on the action set ("give" and "take") and on the origin of endowment ("earned" and "unearned"). Hoffman et al. (1996) introduced a double-anonymity dictator game by adding a subject-experimenter anonymity treatment to the conventional between-subjects anonymity treatment. They found that under single anonymity, 46% of dictators donate at least $3 of a $10 pie, while under double anonymity only 16% of dictators donate at least $3. Forsythe et al. (1994) compared the results from ultimatum and dictator games. The results show that in dictator games only 22% of the players gives an equal share or better to recipients, while in ultimatum games that percentage raises to 65%. Given the different outcomes, they concluded with a rejection of the fairness hypothesis, under which, "if nontrivial offers are due solely to proposal's concerns with fairness, the distribution of the offers should be the same in the two games". For a more general discussion about the interpretation of the results from dictator and ultimatum games, see also Camerer and Thaler (1995).

By testing human choices within ultimatum and dictator games, all these experiments defined pure altruism as a willingness to donate part or the entire endowment to another individual, independently from his characteristics. In daily real-life activities, other forms of other-regarding preferences can be observed. My experiment investigates the presence of prosocial behaviors in accident prevention by testing individual willingness to expend resources to prevent a monetary loss to another individual.

5.1.2 Neuroscientific Literature on Emphatic Behaviors

Empathy, that is the capacity of an individual to understand what another individual is experiencing, has attracted a growing attention from neuroscientific scholars. Recent neuroimaging studies measuring brain activities showed that observing others in pain activates areas of the brain similar to those experiencing pain (Singer et al., 2004; Singer et al., 2006; Cheng et al., 2007; Singer et al., 2008; Akitsuki and Decety, 2009). Among others, Singer et al. (2004) investigated pain-related empathy in 16 couples, under the assumption that couples are likely to feel empathy for each others. They assessed brain activity in the female partner while painful stimulation was applied to her or to her partner's right hand through an electrode attached to the back of the hand. They were interested in comparing pain-related brain activity in the context of "self" and "other." Their results provided more evidence on pain-related empathic responses and showed that empathic experience does not involve activation of an entire pain matrix, but only of that component associated with the affective dimension of pain experience. In a more recent study, Singer et al. (2006) found that male participants who perceived the suffering person as being unfair in a monetary exchange game showed a desire for revenge instead of an empathic response.

Other related contributions have investigated whether individuals are more likely to help an ingroup member rather than an outgroup member in similar need (Levine et al., 2005; De Dreu et al., 2010; Hein et al., 2010). The empirical evidence is mixed. Lanzetta and Englis (1989) found that subjects may even take pleasure in the outgroup member's suffering. Results depend on how ingroup members evaluate outgroup members. My experiment is related to this literature on emphatic behavior: individuals may understand what another individual will experience if an accident happens, and would try to avoid the accident by investing in precautions. It would be interesting to extend my experimental design to include pain-and-suffering damages, and to compare the results with the neuroscientific contributions on pain-related emphatic responses.

5.1.3 Experimental Literature on Accident Law

This study aims primarily at investigating prosocial behaviors in a specific risky context (i.e., a car accident). The implications of the results add to the contributions on other-regarding and prosocial preferences. In addition, this study relies on and ultimately contributes to the experimental literature on liability rules. Despite the extensive number of tort models, we know very little about actual precautionary behaviors under different liability rules, partly because this behavior is difficult to observe unless an accident really happens.[42] Even if experiments are becoming a growing methodology in the toolbox of law and economics scholars (Arlen and Talley, 2008), experiments on tort law is one of the least developed applications of experimental methodology in the study of law. Until now, a small literature (five previous contributions) has experimentally investigated the deterrent effects of specific legal rules, and compared the outcomes with the theoretical predictions.[43] This section briefly reviews the results from these contributions.

The first paper in this area, Kornhauser and Schotter (1990), compared the strict liability rule with the negligence rule in terms of care incentives in a single-actor accident context. In Kornhauser and Schotter (1990), all participants were potential injurers, and their outcome depended only on their own chosen level of care (unilateral-care model). Relying on the theoretical results, the authors tested three hypotheses. First, if the due standard of care is set at the socially optimal level, then a prospective injurer has the same precautionary incentives under both the negligence and the strict liability rules. Secondly, if the due standard of care is set slightly above the socially optimal level, then potential injurers will adhere to the standard, but if it is set sufficiently above the socially optimal level, then rational economic agents will abandon it by choosing a level of care consistent with the strict liability rule. Thirdly, if the standard of due care is set at the socially optimal level, then economic agents will always engage in more

[42]For a review of the empirical research on tort law, see Van Velthoven (2009).

[43]Other contributions have experimentally tested the general assertion that tort liability deters individuals from undertaking potentially harmful activities. See Kötz and Schaefer (1993), Cardi et al. (2012), Eisenberg and Engel (2012), and the references therein.

potentially dangerous activities under the negligence rule rather than under strict liability. They found neither the predicted efficiency equivalence between strict liability and simple negligence, nor the predicted difference in activity levels following which subjects would have chosen more activity level under simple negligence than under strict liability. Specifically, in all strict liability experiments, participants chose excessively high levels of care in the early rounds, and then decreased them as the experiment progressed. At the end, care levels were significantly less than those predicted by the theory. On the contrary, under the negligence rule, participants behave according to the predictions of the theory. Kornhauser and Schotter (1992) compared simple negligence and negligence with contributory negligence defense in a two-actor accident context.[44] They found those rules to be equivalent when the standard of due care is set at the socially optimal level. The rule of negligence with contributory negligence dominates simple negligence when the actors were allowed to choose the intensity of the risky activity. However, neither class of rules performs well in terms of efficiency when individuals were asked to choose both the level of care and the level of activity. Finally, as the theory predicts, the agent who bears the loss in equilibrium has incentives to reduce the level of activity, and, contrary to what expected, the amount of information the subjects have on others' care choices does not increase the efficiency of any rule.

[44]The authors tested four hypotheses, three based on the theoretical analysis of accident law, and one posed by their experimental design. First, when the standard of due care is set at the socially optimal level, rules of negligence and rules of negligence with contributory negligence induce equivalent choices of care. Secondly, agents choose a lower level of risky activity if they bear the costs of the accidents in equilibrium. Thirdly, if the standard of due care increases, the agents will adhere to it up to a certain point, and then abandon it. Fourthly, providing information about the others' care levels yields to outcomes that are more efficient (or at least closer) to the equilibrium.

LeighAnne and Crevier (1992) compared the contributory negligence defense with comparative negligence in a two-actor accident model. The number of observations collected (eight subjects, five periods, and non-computerized classroom setting) were not sufficient to draw any conclusion. Wittman et al. (1997) compared negligence with contributory negligence, comparative negligence, and no-fault rules in a dynamic perspective to detect which of them *more rapidly* achieves the efficient equilibrium. Their experiment strongly confirms both equilibrium and learning theory. They found that no-fault rules lead to suboptimal levels of care, and that comparative negligence and negligence with contributory negligence achieve the same (efficient) equilibrium, with a faster convergence under comparative negligence.

Angelova et al. (2013) analyzed the investments in safety under no liability, strict liability and simple negligence, and compared them to the first best. Their context is different from the previous ones: they investigated which liability rule is more efficient in reducing the probability that a firm harms third parties (i.e., the environment or individuals). They found that strict liability and simple negligence are equally effective (in contrast with the results in Kornhauser and Schotter, 1990), and both perform better than no liability. Moreover, the investment in safety is not sensitive to the financial ability of the firm to compensate potential victims.

5.2 Experimental Model and Hypotheses

This section presents the standard unilateral-care accident model and describes the equilibrium properties of the liability rules. The theoretical results provide the hypotheses for the experiment.

The standard economic model of accident law relies on three basic elements: the cost of harm, the cost of avoiding harm, and the benefit of socially valuable activities (e.g., driving cars, manufacturing, practicing medicine). There are two parties, a prospective tortfeasor and his victim, that are assumed to be stranger to each other, risk-neutral, and free from any type of behavioral bias. Parties undertake a risky but —socially and individually— desirable activity, and invest in costly levels of care to reduce the probability of an accident. My analysis focuses on precautionary choices, and thus considers activity levels as exogenous. Following the conventional notation, let x and y denote the tortfeasor's and victim's care levels respectively, and $\bar{z}$ and $\bar{u}$ denote the tortfeasor's and victim's activity levels respectively.

Let us assume that both parties' utilities decrease in care level at a constant or increasing rate, and increase in activity level at a decreasing rate. Let $w = e(\bar{z}) - c(x)$ be the injurer's level of wealth, and let $b = e(\bar{u}) - c(y)$ be the victim's wealth. Following the standard assumptions of tort models, I assume the following relationships: $c_x > 0, c_{xx} \geq 0$ for the tortfeasor, and similarly $c_y > 0, c_{yy} \geq 0$ for the victim. Given exogenous activity levels, $e(\bar{z})$ and $e(\bar{u})$ are interpreted as the parties' initial endowments.

Let us now turn to the cost of accidents. The probability of an accident decreases as parties increase their care levels at a constant or increasing rate, i.e., $p_x < 0$, $p_{xx} \geq 0$ for the tortfeasor, and $p_y < 0$, $p_{yy} \geq 0$ for the victim. The accident loss is denoted by $L > 0$.

5.2.1 Social Problem

The socially optimal levels of care are derived as solutions of the social optimization problem. The social welfare function is defined as the sum of parties' utilities, net of the expected cost of the accident. In a unilateral framework where the accident rates depend only upon the behavior of one party, the social optimization problem is defined as follows:

$$\max_a S = e(\bar{z}) + e(\bar{u}) - c(a) - p(a)L \tag{5.2.1}$$

where $a \in \{x, y\}$ depending on which of the two parties can prevent an accident by undertaking care measures. The socially optimal care levels a^{**}, with $a^{**} \in \{x^{**}, y^{**}\}$, satisfy the following first-order conditions:

$$c_a = -p_a L \tag{5.2.2}$$

According to this condition, the socially optimal care levels are the levels at which the marginal benefit from an increase in care investments (i.e., the reduction in the expected accident costs, $-p_a L$) equals the marginal care cost (c_a).

The next step is to define the private maximization problems under the no liability rule and the strict liability rule. The main results are pointed out as hypotheses for the experiment.

5.2.2 Private Problem

The expected private utility functions are given by individual benefits from the activity at the net of the cost of precaution and of the expected cost of accident. Let T and V denote the expected utilities of the tortfeasor and of the victim. The private optimization problems can be defined as follows:

$$\max_{x} T = e(\bar{z}) - c(x) - \sigma\, p(a)\, L \tag{5.2.3}$$

$$\max_{y} V = e(\bar{u}) - c(y) - (1-\sigma)\, p(a)\, L \tag{5.2.4}$$

where $a \in \{x, y\}$, and $\sigma \in \{0, 1\}$ is the share of the loss borne by the injurer under the liability rule in place. More specifically, $\sigma = 0$ under the no liability rule, and $\sigma = 1$ under the strict liability rule.[45]

Let us consider the precautionary choices of the parties when they can influence the probability of an accident. The privately optimal care levels under no liability, denoted by x^*_{nl} for the injurer and by y^*_{nl} for the victim, are respectively defined by the following

[45] For a review of the standard Calabresi-Brown model, see the pioneering work by Brown (1973) and the recent review of the economic analysis of liability rules by Dari-Mattiacci (2005).

first-order conditions:

$$c_{x_{nl}} = 0 \tag{5.2.5}$$

$$c_{y_{nl}} = -p_{y_{nl}} L \tag{5.2.6}$$

By comparing (5.2.5) and (5.2.6) with the socially optimal levels, it follows that $x^*_{nl} = 0 < x^{**}$ and $y^*_{nl} = y^{**}$. As standard in the literature, under the no liability rule potential injurers have no incentives to invest in care since they will never have to compensate the victim in case of accident. By contrast, potential victims have correct incentives to undertake socially optimal care levels to minimize the expected accident costs.

At the exact opposite, under the strict liability rule, σ is equal to 1, and the privately optimal care levels, i.e., x^*_{sl} for the injurer and y^*_{sl} for the victim, are respectively defined as follows:

$$c_{x_{sl}} = -p_{x_{sl}} L \tag{5.2.7}$$

$$c_{y_{sl}} = 0 \tag{5.2.8}$$

In this case, the victim has no incentives to exercise care since any monetary loss will be compensated, i.e., $y^*_{sl} = 0 < y^{**}$, whereas the injurer fully internalizes the benefit of precautions $x^* = x^{**}_{sl}$.

5.2.3 Hypotheses

The comparison between the privately optimal care levels of the two parties reveals the symmetric properties of the two rules. Since parties are assumed to be identical except for their role, potential injurers under the strict liability rule have the same precautionary incentives as potential victims under the no liability rule, i.e., $x^*_{sl} = y^*_{nl} = a^{**}$ where a^{**} is the socially optimal level of care defined in (5.2.2). Similarly, potential injurers under the no liability rule have no incentives to undertake precautions, as potential victims under the strict liability rule, i.e., $x^*_{nl} = y^*_{sl} = 0$. Thus, in the aggregate, victims and injurers under the two rules are expected to invest in the same aggregate level of care. Table 5.1 summarizes the theoretical results of the standard accident model.

	Victim	*Injurer*
No Liability	$c(y^*_{nl}) = c(y^{**})$	$c(x^*_{nl}) = 0 < c(x^{**})$
Strict Liability	$c(y^*_{sl}) = 0 < c(y^{**})$	$c(x^*_{sl}) = c(x^{**})$

Table 5.1: *Socially* vs. *Privately Optimal Care Expenditures*

The hypotheses to be tested in the experiment essentially derive from two sources: the economic theory on liability law outlined above in this section, and the experimental results on prosocial behaviors and other-regarding preferences reviewed in the introductory sections. The first three hypotheses aim to test the theoretical predictions on equilibrium care choices and to detect possible behavioral biases.

Hypothesis 5.2.1 (Care Expenditures per Role)**.** *Potential injurers have higher precautionary incentives under the strict liability rule rather than under the no liability* *rule, i.e.,* $c(x^*_{sl}) > c(x^*_{nl})$*. Potential victims have higher precautionary incentives under the no liability rule rather than under the strict liability rule, i.e.,* $c(y^*_{nl}) > c(y^*_{sl})$*.*

Hypothesis 5.2.2 (Equivalence of Roles per Liability Rule)**.** *Potential injurers under the strict liability rule and potential victims under the no liability rule undertake the same care level. Formally,* $c(x^*_{sl}) = c(y^*_{nl})$*. Potential injurers under the no liability rule and potential victims under the strict liability rule undertake the same care level. Formally,* $c(x^*_{nl}) = c(y^*_{sl})$*.*

Hypothesis 5.2.3 (Equivalence of Roles)**.** *Under mirrored liability rules, potential victims and potential injurers invest in the same aggregate level of care measures. Formally,* $c(x^*_{sl}) + c(x^*_{nl}) = c(y^*_{sl}) + c(y^*_{nl})$*.*

Hypothesis 5.2.1 tests whether individuals undertake more precautions when burdened by liability costs. Hypotheses 5.2.2 and 5.2.3, that are the most relevant for this study, test the theoretical prediction of symmetrical care choices of potential injurers and victims under alternative mirrored liability rules. These hypotheses, if not rejected, imply that individuals are equally averse between suffering a loss and causing a loss to others.

However, moral sentiments and prosocial behaviors could lead individuals to evaluate the cost of others' losses as higher than their own losses in a context where they feel responsible for that loss (Charness, 2000; Charness and Jackson, 2009). In a risky context, this implies that individuals might spend more resources to avoid causing a loss to others rather than to avoid suffering a loss per se. By relying on the experimental results on prosocial and other-regarding preferences, we would expect individuals to make different care choices depending upon their role in an accident. More specifically, under mirrored liability rules, I would expect potential injurers to expend more resources in care measures than victims. These considerations lead to the following hypotheses.

Hypothesis 5.2.4 (Prosocial Preferences)**.** *Subjects care about the others' monetary loss, regardless of their role in the accident, i.e.,* $c(x^*_{nl}) + c(y^*_{nl}) > 0$. *Subjects care more about the others' monetary loss rather than their own, regardless of their role in the accident, i.e.,* $c(x_{nl^*}) + c(y^*_{sl}) > c(x_{sl^*}) + c(y^*_{nl})$.

Hypothesis 5.2.5 (Prosocial Preferences and Nonequivalence of Roles)**.** *Subjects spend more resources to avoid causing a monetary loss to others rather than to avoid suffering a monetary loss. In the aggregate, potential injurers expend more resources in care measures than potential victims, i.e.,* $c(x^*_{sl}) + c(x^*_{nl}) > c(y^*_{sl}) + c(y^*_{nl})$.

5.3 Experimental Design and Parameters

This study asks individuals to trade off profits from themselves against monetary losses either for themselves or for another person. To test the hypotheses outlined in Section 5.2, I ran two sessions of a paper-based experiment. The participants were all undergraduate students in economics: 109 students were recruited from the University of Bologna for the first session, and 115 students were recruited from the University of Modena and Reggio Emilia for the second session, for a total of 224 participants.

The decisions of participants who incorrectly replied to at least one of the three check questions in the instructions were not considered. Thus, the final analysis was carried out considering the choices of 208 participants.

In unilateral-care accident models, the probability of an accident depends only upon the behavior of one party, either the injurer (i.e., $p(x)$), or the victim (i.e., $p(y)$). Let us denote the party who can invest in precautions the "active player", and the party who cannot take any action to prevent an accident the "passive player". In these two sessions all the participants were active players.

The experiment used a between-subject, 2 x 2 design, with two liability rules for each role. Each participant was assigned the role of *injurer* or *victim* (role treatment), and was asked to take decisions under both the *strict liability* rule and the *no liability* rule (liability-rule treatment). Each session lasted approximately 20 minutes. Payoffs were denominated in a fictitious currency called points and denoted with the symbol §. Participants received non-monetary incentives to participate in the experiment, that is, extra-points for the final grade of the course exam.

5.3.1 Roles and Task

At the beginning of the experiment, participants were randomly assigned either the role of injurer or the role of victim. The roles were privately communicated and remain fixed through the experiment. All the participants were active players and were assigned the role of car drivers. Each subject was asked to decide whether and how many precautions he would like to undertake to reduce the accident rate. Each active player was informed that his precautionary choices would have influenced the probability of an accident involving another subject that could not do anything to prevent it (the passive player). The probability of an accident was computed on the basis of the active parties' precautionary investments. The identity of the subjects and their individual investment in care remained private information, and no feedback concerning the happening of the accident was provided during the study.

5.3.2 Parameters

At the beginning of each treatment, participants received an initial endowment of §140. In each treatment, subjects were asked to decide whether and how many precautions they would like to undertake in a range from 0 to 6 care units. A marginal investment in care reduces the probability of an accident by 10%, and entails an increasing marginal cost. The probability of an accident is expressed by the following function: $p(a) = 0.85 - 0.10a$, where $a = x \in [0,6]$ if the injurer is the active player, or $a = y \in [0,6]$ if the victim is the active player. The probability of loss thus ranges between 25% (if the active player invests in the maximum amount of precautions, i.e., 6) and 85% (if the active player undertakes zero precautions). The cost of precautions is defined by the following function: $c(a) = 4a + a^2$, with $a = x, y \in [0,6]$. The cost of precautions ranges from 0 (when the active players invests in zero precautions) to 60 (when the active player invests in the maximum amount of precautions). If the accident happens, the (fixed) monetary loss will be of §80. Negative payoffs were not possible.

Table 5.2 summarizes the parameters set in this experimental design:

Parameter	Value	Description
$e(\bar{z}),\, e(\bar{u})$	§140	initial endowment
$x,\ y$	$\in [0,6]$ units	care levels
$c(a) = 4a + a^2;\, a = x,y$	$\in [0,60]$	cost of care
$p(a) = 0.85 - 0.10a;\, a = x,y$	$\in [0.25, 0.85]$	probability of an accident
L	§80	accident loss

Table 5.2: *Parameters of the Experimental Design*

5.3.3 Predictions

This section revisits the Hypotheses outlined in Section 5.2 on the basis of the parameters set in the experimental design. From (5.2.2), it follows that the socially optimal care level is 2. Given (5.2.7) and (5.2.6), the theory predicts that potential injurers under the strict liability rule and victims under the no liability rule will undertake socially optimal care levels, i.e., $x^*_{sl} = y^*_{nl} = 2$. In this case, the optimal expenditure in precautions is §12. Similarly, given (5.2.5) and (5.2.8), the standard results imply that potential injurers under the no liability rule and victims under the strict liability rule will have no incentives to undertake precautions, i.e., $x^*_{nl} = y^*_{sl} = 0$, or at least less incentives than they would have in the presence of expected liability costs (Hypotheses 5.2.1 and 5.2.2). Under Hypothesis 5.2.3, injurers and victims should undertake in aggregate the same level of precautions, i.e., $x^*_{sl} + x^*_{nl} = y^*_{nl} + y^*_{sl} = 2$. In other words, the aggregate care expenditure should be §12 for both injurers and victims. Table 5.3 summarizes the optimal precautionary expenditures under the alternative liability rules considered, given the parameters of the experimental design.

	Victim	*Injurer*
No Liability	$c(y^*_{nl}) = c(y^{**}) = \S 12$	$c(x^*_{nl}) = \S 0 < c(x^{**})$
Strict Liability	$c(y^*_{sl}) = \S 0 < c(y^{**})$	$c(x^*_{sl}) = c(x^{**}) = \S 12$
Aggregate	$c(y^*_{nl}) + c(y^*_{sl}) = \S 12$	$c(x^*_{nl}) + c(x^*_{sl}) = \S 12$

Table 5.3: *Socially* vs. *Privately Optimal Care Expenditures in the Experiment*

5.4 Results

This section presents the results of the experiment in relation to the underlying hypotheses. Before discussing the results, Table 5.4 provides the descriptive statistics by presenting the mean, medians and standard deviations of subjects' care expenditures.

$t = 0$ *(victims)*

				— *Quantiles* —				
Liability Rule	*N*	*Mean*	*S.D.*	*Min*	*.25*	*Mdn*	*.75*	*Max*
no liability	104	27.48	20.65	0.00	12.00	21.00	45.00	60.00
strict liability	104	21.07	20.72	0.00	0.00	21.00	32.00	60.00
aggregate	208	48.55	32.53	0.00	32.00	45.00	66.00	120.00

$t = 1$ *(injurers)*

				— *Quantiles* —				
Liability Rule	*N*	*Mean*	*S.D.*	*Min*	*.25*	*Mdn*	*.75*	*Max*
no liability	104	17.01	18.62	0.00	0.00	12.00	32.00	60.00
strict liability	104	20.53	18.48	0.00	0.00	21.00	32.00	60.00
aggregate	208	37.54	31.07	0.00	12.00	33.00	60.00	120.00

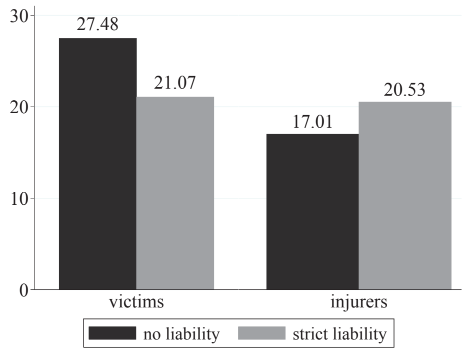
Table 5.4: *Summary statistics for care expenditures*

Table 5.4 suggests that on average subjects in each role and under each rule invest in more than optimal care levels. It can be noticed also that individuals expend resources to prevent an accident even when they were not burdened by the expected liability costs (i.e., victims under the strict liability rule and injurers under the no liability rule). This can be interpreted as a natural propensity to care about the others' monetary losses, even when this comes at own expenses (see Hypothesis 5.2.4). This result is consistent with the extant literature on other-regarding preferences in predicting individuals' aversions to bad outcomes especially when these affect others' well-being. Table 5.4 suggests also that care expenditures were higher when subjects were burdened by the expected accident costs, i.e., $c(x^*_{sl}) > c(x^*_{nl})$ for the injurers and $c(y^*_{nl}) > c(y^*_{sl})$ for the victims (see Hypothesis 5.2.1).

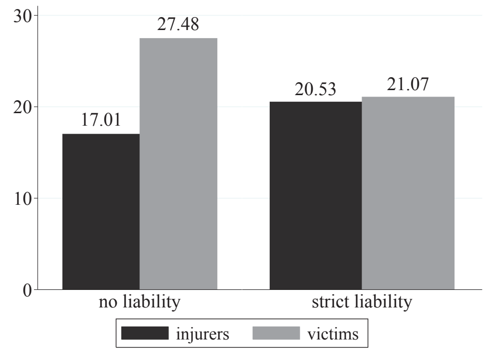
To assess whether these differences are significant, I compare pairwise the two distributions using Wilcoxon signed rank sum tests and sign tests (see Tables 5.5 and 5.6 in Appendix 5.6). The distributions of care investments are (i) significantly different from the predicted care levels; (ii) significantly lower under the no liability rule rather than under the strict liability rule for injurers (sign test, p-value = 0.0843); (iii) significantly lower under the strict liability rule rather than under the no liability rule for victim (sign test, p-value = 0.0008). On the basis of these results, Hypothesis 5.2.1 on care choices per role under the two liability rules cannot be rejected.

To better appreciate differences in investment patterns across the treatments, Figure 5.1 plots the average investments in care measures.

Both graphs in Figure 5.1 show that subjects' investment in care measures is higher than the predicted values. More specifically, Figure 5.1a shows that care expenditures are higher in the presence of expected liability costs, as the theoretical results predict. Victims have spent on average §27.48 in precautions under the no liability rule against the §21.07 spent under the strict liability rule. Injurers have spent on average §20.53 in safety under the strict liability rule against the §17.01 spent under the no liability rule.



(a) *per role*



(b) *per liability rule*

Figure 5.1: *Average Care Investments by Treatment*

Figure 5.1b highlights the fact that on average potential victims undertook approximately the same level of precautions of injurers under the strict liability rule (§21.07 spent by victims and §20.53 spent by injurers).

Figure 5.1b shows the most interesting and surprising result of this experiment:

Result 5.4.1. *Under the strict liability rule, victims invest about as much as injurers.*

Victims under the strict liability rule heavily invest in care measures, even if perfectly insured. Indeed, on average, under the strict liability rule, victims invested about as much as injurers (§21.07 spent by victims and §20.53 spent by injurers). Note that in the "Victim, Strict Liability" case, (a) injurers have to pay whenever damage occurs, but (b) only victims can take actions to prevent the accident. In other words, victims are the active players and are perfectly insured against accident losses. From a theoretical point of view, we would have expected victims to undertake zero precautions or at least less precautions than injurers in the "Injurers, Strict Liability" case. Surprisingly, we found that victims invested about as much as injurers. This result could have been driven by different motivations. First, it can be interpreted as another instance of social preferences: the victims see it as unfair to make injurers loose money with such a high probability, and heavily invest in precautions in order to prevent unjust liability for injurers. Another interpretation is related to the fact that only victims suffer the damage to their property. In this case, the willingness to protect personal properties might prevail over the compensation damages. In other words, victims care about their own personal properties, regardless of the compensatory system in place in case of damages.

Considering now the no liability rule, I found the following result:

Result 5.4.2. *Under the no liability rule, victims invest much more than injurers.*

This is coherent with the theoretical models of accident law (Shavell, 1980). Around 40% of injurers spend nothing to avoid causing an accident. Given that injurers in this case are essentially playing a risky dictator game, this result can be seen as coherent with the standard findings in dictator games in which on average around 36% of all dictators give nothing to the recipient (Engel, 2011). These results show that injurers in the "Injurer, No Liability" case nonetheless undertake on average more than 60% of victims' investments in the "Victim, No Liability" case. This can be interpreted as another instance of social preferences: given that, in the "Injurer, No Liability" case, victims cannot take actions to avoid the accident, injurers feel it as unfair to make victims suffering unjust and uncompensated losses.

Furthermore, Figure 5.1a shows that care expenditures are higher in the presence of expected liability costs, as the theoretical results predict (i.e., Hypothesis 5.2.1 cannot be rejected). Victims have spent on average §27.48 in precautions under the no liability rule against the §21.07 spent under the strict liability rule. Injurers have spent on average §20.53 in safety under the strict liability rule against the §17.01 spent under the no liability rule.

Result 5.4.3. *Subjects invest more in precautions in the presence of expected liability costs. Victims undertake more precautions under the no liability rule rather than under the strict liability rule, and injurers undertake more precautions under the strict liability rule rather than under the no liability rule.*

Potential injurers and victims undertake care levels even when it would be desirable to not undertake them. More specifically, we would have expected potential injurers and victims to invest in zero precautions when they were not burdened by expected liability costs (i.e., under the no liability rule and the strict liability rule respectively). The results show that individuals have incentives to deviate from the zero-care equilibria (see Tables 5.5 and 5.6 for the Wilcoxon signed rank-sum tests and sign tests in Appendix 5.6) suggesting that people care about the others' monetary losses. However, when comparing the incentives to undertake care measures with and without expected liability costs, it appears that individuals are more willing to invest in care measures when these prevent a monetary loss to self rather than to others, regardless of their role in the accident. Figure 5.2 shows that the total amount of care investments of injurers under the strict liability rule and of victims under the no liability rule ("with liability costs") is significantly greater than the total amount of care investments of injurers under the no liability rule and of victims under the strict liability rule ("without liability costs”), i.e., $c(x_{sl}) + c(y_{nl}) > c(x_{nl}) + c(y_{sl})$ (see Tables 5.5 and 5.6 in Appendix 5.6).

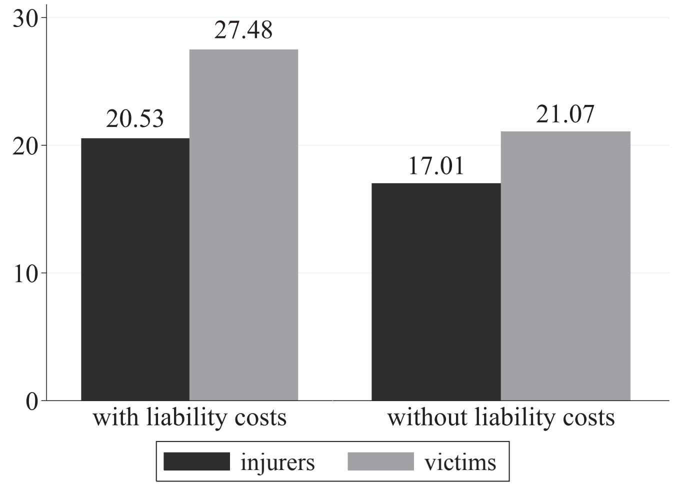


Figure 5.2: *Loss To Self* vs. *Loss To Others*

Following these results, Hypothesis 5.2.4 under which individuals were expected to care about the others’ monetary losses at least as much as their own can be rejected.

Let us now analyze the care choices of injurers compared to the care choices of victims. It has been already shown that parties do not adhere to the predicted equilibrium levels of care and that they invest more in care in the presence of expected liability costs (i.e., Hypothesis 5.2.1 cannot be rejected). The question now is whether there are differences in care investments between injurers and victims. The theoretical model predicts that injurers and victims should have the same precautionary incentives under mirrored liability rules. In other words, people should be expected to expend resources to prevent being the victim of an accident inasmuch as to prevent being the injurer of an accident.

In order to test whether the difference in care choices between injurers and victims is statistically significant, I consider the aggregate care investments under the two liability rules. Hypothesis 5.2.3 states that in aggregate, under mirrored liability rules, the distributions of care choices should be equal between injurers and victims. The Mann-Whitney test is performed to test this prediction. The results in Table 5.7 show that the distribution of care expenses is significantly lower under the role of injurers rather than under the role of victims (Wilcoxon-Mann-Whitney test, p-value = 0.0110 under the hypothesis that $c(x_{sl}) + c(x_{nl}) = c(y_{sl}) + c(y_{nl})$).

To better appreciate differences in investment patterns across the treatment "role", Figure 5.3 plots the kernel-density functions of the aggregate care investments of injures (black line) and of victims (grey line). Figure 5.4 shows the kernel-density plots with the histogram of the aggregate care investments under the two roles.

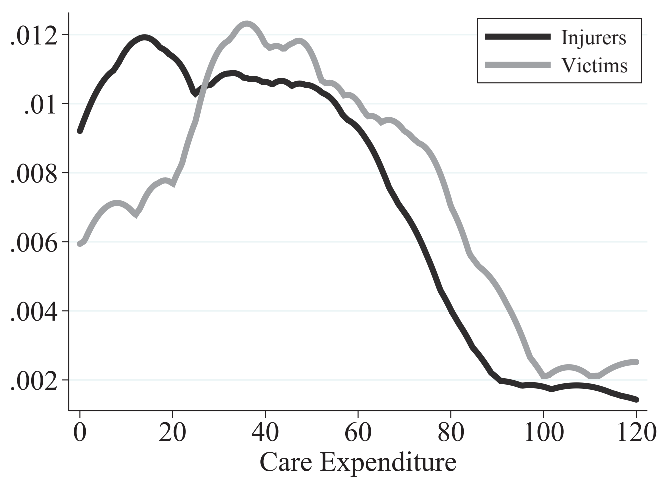


Figure 5.3: *Kernel-Density Plots of the Aggregate Care Levels per Role*

The graphs in Figures 5.3 and 5.4 confirm that subjects do not act as theoretically predicted, and that the care investments are not uniformly distributed across the treat-

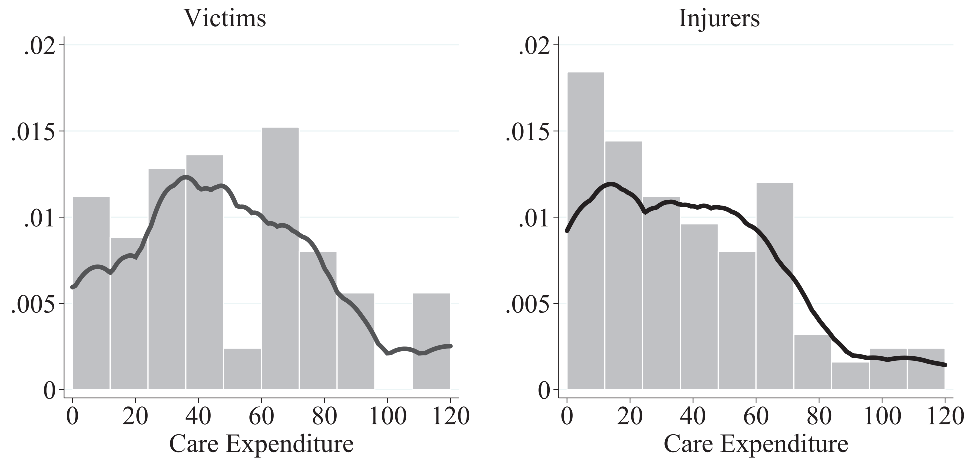


Figure 5.4: *Aggregate Care Levels per Role*

ment “role”. By comparing the two kernel distributions in Figure 5.3, it can be noticed that victims tend to invest less in low care levels and more in medium-high care levels as compared to injurers’ choices. Following this result, Hypothesis 5.2.5 under which individuals were expected to care more about the others’ safety rather than own safety can be rejected.

These results are summarized as follows:

Result 5.4.4. *Most subjects preferred to invest in care measures even when not burdened by expected liability costs, i.e.,* $c(x_{nl}) + c(y_{sl}) > 0$*. Subjects care about the others’ monetary loss, but less than their own. Formally, subjects invest in more precautions when burdened by expected liability costs, regardless of them being injurers or victims, i.e.,* $c(x_{nl}) + c(y_{sl}) < c(x_{sl}) + c(y_{nl})$*.*

Result 5.4.5. *Subjects spend more resources to avoid suffering a loss rather than to avoid causing a loss to others. Formally, potential victims spent more resources* *in precautions than potential injurers to prevent an accident, i.e.,* $c(x_{nl}) + c(x_{sl}) < c(y_{sl}) + c(y_{nl})$.

These tests show that the distributions of care investments are different between injurers and victims. On the basis of the neuroscientific contributions and of the experimental literature on prosocial behavior and other-regarding preferences, individuals should be expected to undertake more precautions to prevent a monetary loss to others rather than to self (Hypothesis 5.2.4). On the contrary, the experimental results show that subjects spent more resources to avoid suffering a loss rather than causing it.

This result is coherent with the contributions on prosocial preferences which show that people care about the others' monetary outcome, but less than their own (Engel, 2011). Nevertheless, the observation of relatively hypoaltruistic behavior in the context of accident prevention suggests that the valuation of others' well-beings is highly context-dependent.

5.5 Implications, Limitations, and Concluding Remarks

This chapter presents an experimental design in which people care more about their own monetary loss than an anonymous stranger's monetary loss and dislike suffering a loss to self more than causing a loss to others, even if their decisions were completely anonymous with no possibility of being punished or otherwise judged.

Consistently with previous studies of social preferences (e.g., Engel, 2011), result 5.4.4 highlights that individuals value the others' monetary loss less than their own.

Result 5.4.5 shows that people spend more resources to avoid suffering a loss rather than to avoid causing a loss to others. This is a novel result which adds to the extant contributions on prosocial preferences, and stands in contrast with the observation that individuals dislike being responsible of bad outcomes, especially when they affect the others' well-being (Ritov and Baron, 1990; Kahneman, 2011). Under this perspective, the added cost of moral responsibility should have led people to value others' losses more than their own.

This experiment adds another perspective to these previous contributions. The results show that individuals are more averse in suffering a loss to self rather than in causing a loss to others. There are several potential explanations for these findings. First, the consequences of subjects' care decisions on others' well-being is uncertain, and people might have biased risk-perceptions depending upon their role in an accident. Potential injurers might be unrealistically optimistic about their ability to avoid an accident, whereas potential victims might perceive unrealistically high rates of risks for themselves (DeJoy, 1989). This could ultimately lead injurers to undertake less precautions than victims. Even when potential victims are not pessimistically biased, they could expect injurers' optimistic bias and compensate their unrealistic risk perceptions by undertaking more precautions.

An alternative explanation stems from the possibly different perception of economic and pain-and-suffering damages (Cohen and Miller, 2003; Avraham, 2015). This experiment considered economic damages and perfect compensation. Potential injurers might become more willing to undertake care measures in the presence of pain-and-suffering damages, but victims might remain more harm-averse especially in case of imperfect compensation of noneconomic damages. The consideration of noneconomic damages might thus either reduce the difference in care investments between injurers and victims or left it unchanged. Future investigations which include pain-and-suffering damages and imperfect compensation may make it possible to analyze the conditions under which my results hold.

A third possibility arises from the fact that in this experiment the monetary loss falls entirely on one of the two subjects. This might lead the victims to undertake more precautions than injurers given the potential threat to their personal property, even if damages are compensated. Injurers, on the contrary, do not suffer any damage to their personal property and are less willing to adopt precautions. For example, a driver might be less averse in causing a damage to another car and pay the compensation, rather than suffering a damage to his own vehicle, even if compensated. The willingness to protect personal properties might prevail over the compensation damages. In other words, individuals care about own personal properties, regardless of the compensatory system in place in case of damages.

Other questions still have to be answered, opening the possibility for further research on this topic. One of them is whether the results of my experiment would generalize to a bilateral-care model. In unilateral-care accidents, only one of the two subjects can reduce the probability of an accident by undertaking precautions, while the other subject is completely passive. In bilateral-care accidents, both parties' decisions affect the probability of an accident. Results might substantially change if subjects know that also others can invest in care to avoid an accident. Determining how people behave under different accident frameworks remain an empirical question.

Future research and field methods might explore the boundaries of subjective valuations of harm in an accident setting by varying the parameters of this study. For example, it is possible that the "aversion-to-suffer" found in this research is limited to harms of medium consequences (in this experiment, the damages amount to §80 on §140 of initial endowment); to property damages; and to a relatively wide probability of having an accident (in this experiment, the probability of an accident ranges from 25 to 85 percent). Other extensions might also include the uncertainty of being victims or injurers in an accident, and the possibility that also injurers suffer a share of the loss together with the victims. Different results might also arise when distinguishing the care choices by male and female participants.

This study provided a novel context for testing moral preferences and investigating antisocial behaviors. The results show a greater aversion to be injured rather than to cause a loss. Understanding the boundary conditions of this observation has implications for many legal and political decisions about social interactions in risky situations.

5.6 Appendix A: Tables

H_0	z	$Prob>\|z\|$
$c(x_{sl}) = 12$	3.257	0.0011
$c(y_{nl}) = 12$	5.657	0.0000
$c(x_{nl}) = 0$	7.660	0.0000
$c(y_{sl}) = 0$	7.769	0.0000
$c(x_{sl}) = c(x_{nl})$	1.599	0.1098
$c(y_{sl}) = c(y_{nl})$	2.958	0.0031
$c(x_{sl}) + c(y_{sl}) = c(x_{nl}) + c(y_{nl})$	3.308	0.0009
$c(x_{sl}) + c(x_{nl}) = c(y_{sl}) + c(y_{nl})$	12.176	0.0000

Table 5.5: *Wilcoxon Signed-Rank Tests*

H_0	H_a	*p-value*
	mdn of $c(x_{sl}) - 12 > 0$	0.0057
mdn of $c(x_{sl}) - 12 = 0$	mdn of $c(x_{sl}) - 12 < 0$	0.9969
	mdn of $c(x_{sl}) - 12 != 0$	0.0115
	mdn of $c(y_{nl}) - 12 > 0$	0.0000
mdn of $c(y_{nl}) - 12 = 0$	mdn of $c(y_{nl}) - 12 < 0$	1.0000
	mdn of $c(y_{nl}) - 12 != 0$	0.0000
	mdn of $c(x_{nl}) > 0$	0.0000
mdn of $c(x_{nl}) = 0$	mdn of $c(x_{nl}) < 0$	1.0000
	mdn of $c(x_{nl}) != 0$	0.0000
	mdn of $c(y_{sl}) > 0$	0.0000
mdn of $c(y_{sl}) = 0$	mdn of $c(y_{sl}) < 0$	1.0000
	mdn of $c(y_{sl}) != 0$	0.0000
	mdn of $c(x_{sl}) - c(x_{nl}) > 0$	0.0843
mdn of $c(x_{sl}) - c(x_{nl}) = 0$	mdn of $c(x_{sl}) - c(x_{nl}) < 0$	0.9483
	mdn of $c(x_{sl}) - c(x_{nl}) != 0$	0.1686
	mdn of $c(y_{nl}) - c(y_{sl}) > 0$	0.0008
mdn of $c(y_{nl}) - c(y_{sl}) = 0$	mdn of $c(y_{nl}) - c(y_{sl}) < 0$	0.9997
	mdn of $c(y_{nl}) - c(y_{sl}) != 0$	0.0016
	mdn of $c(x_{sl}) + c(y_{nl}) > c(x_{nl}) + c(y_{sl})$	0.0005
mdn of $c(x_{sl}) + c(y_{nl}) = c(x_{nl}) + c(y_{sl})$	mdn of $c(x_{sl}) + c(y_{nl}) < c(x_{nl}) + c(y_{sl})$	0.9997
	mdn of $c(x_{sl}) + c(y_{nl}) != c(x_{nl}) + c(y_{sl})$	0.0010
	mdn of $c(x_{sl}) + c(y_{nl}) > c(x_{nl}) + c(y_{sl})$	0.0005
mdn of $c(x_{sl}) + c(y_{nl}) = c(x_{nl}) + c(y_{sl})$	mdn of $c(x_{sl}) + c(y_{nl}) < c(x_{nl}) + c(y_{sl})$	0.9997
	mdn of $c(x_{sl}) + c(y_{nl}) != c(x_{nl}) + c(y_{sl})$	0.0010

Table 5.6: *Sign Tests*

t	obs	rank sum	expected
0	104	11967	10868
1	104	9769	10868
combined	208	21736	21736

unadjusted variance 188378.67
adjustment for ties -1345.47
adjusted variance 187033.20

Ho: $c(y_{sl}) + c(y_{nl}) = c(x_{sl}) + c(x_{nl})$
z = 2.541
Prob > |z| = 0.0110

Table 5.7: *Two-Sample Wilcoxon Rank-Sum (Mann-Whitney) Test*

5.7 Appendix B: Instructions

5.7.1 Instructions for Injurers

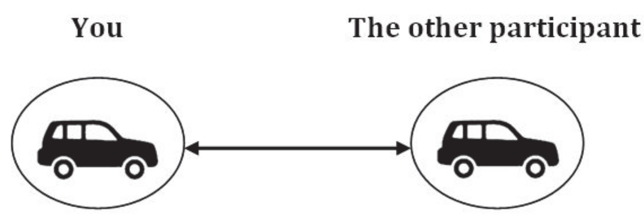
A short study on decision making

We are conducting a survey about care choices. The time needed to complete this survey is approximately 30 minutes. **Please read the instructions carefully**.

Imagine that you have an **initial portfolio of 140 points**. Your choices in the survey and chance will influence your final portfolio and also the final portfolio of another participant. For your participation in this study, you will receive extra-points for the final grade of the course exam.

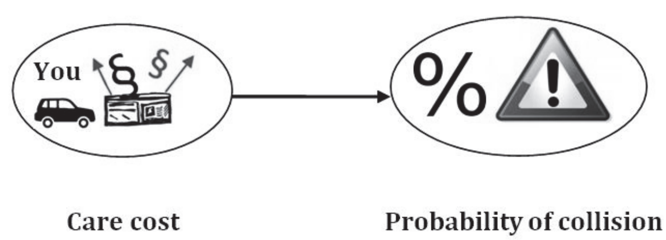
You are randomly **matched with another participant**, whose identity will remain private information.

Both you and the other participant have been assigned the role of drivers.



Your task is to decide **how much you want to invest in precautions to avoid a collision causing an economic damage to the other participant's car**.

The more precautions you take, the higher the cost for you, but the lower the probability of causing an economic damage to the other participant's car.



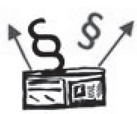
The other participant cannot take any precaution to avoid the collision.

Scenario 1

If the accident happens, **you will not have to compensate the other participant** for the economic damage you caused to his/her car.

You can decide how many points you want to spend in precautions.

- Please look at the first row of the table, you can decide to spend zero points in precautions. In this case you get the initial earning (§140) and do not suffer any cost of care. If you invest zero in precaution, the collision happens with a probability of 85%.
- Look at the second row, investing 5 points in precautions reduces the probability of collision to 75%, and your final earning will be 140 - 5 = §135.
- Look at the bottom row of the table, investing 60 points reduces the probability of collision to 25%, and your final earning will be 140 - 60 = §80.

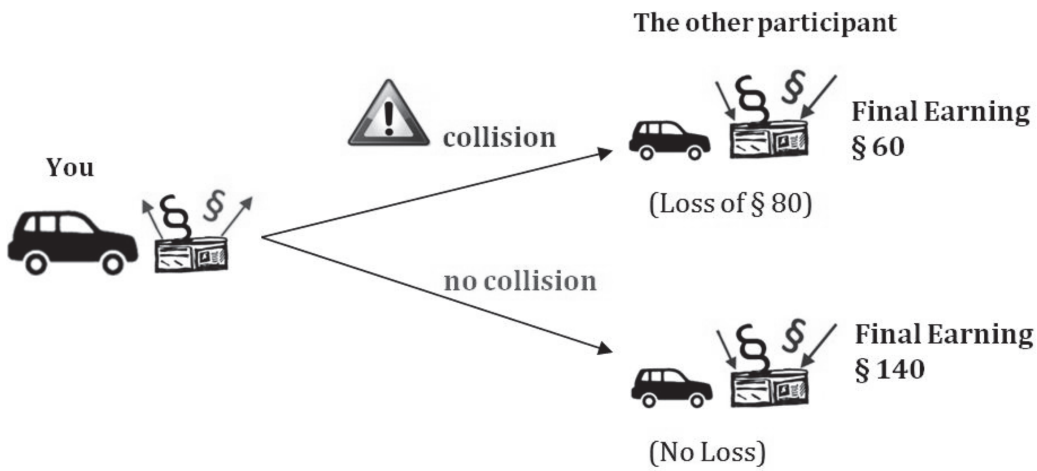
Cost of Care 	Your Final Earning You 	Prob% Collision 
§ 0	§ 140	85%
§ 5	§ 135	75%
§ 12	§ 128	65%
§ 21	§ 119	55%
§ 32	§ 108	45%
§ 45	§ 95	35%
§ 60	§ 80	25%

The economic damage to the other participant's car in case of collision amount to §80.

If an accident happens, the other participant bears the loss you caused to his/her car.

If the accident happens, the final earning of the other participant will be 140 - 80 = §60.

If the accident does not happen, the other participant keeps the initial endowment of §140.



Let consider the following example. Imagine that you decide to invest 5 points in precautions:

- The probability of a collision is 75%;
- Whether the accident happen or not, your final earning will be 140 [initial points] - 5 [cost of precautions] = §135, since you never pay to compensate the other participant;
- The other participant will earn §140 [initial earning points] if the accident does not happen, or 140 - 80 [accident cost] = §60 if the accident happens since the victim will not receive any compensation for the accident loss.

Your Initial Endowment	Cost of Care	Prob% Collision	Your Final Earning	The Other Participant's Earning
§ 140	- § 0	**85% accident**	**§ 140**	**§ 60**
		15% no accident	§ 140	§ 140
§ 140	- § 5	**75% accident**	**§ 135**	**§ 60**
		25% no accident	§ 135	§ 140
§ 140	- § 12	**65% accident**	**§ 128**	**§ 60**
		35% no accident	§ 128	§ 140
§ 140	- § 21	**55% accident**	**§ 119**	**§ 60**
		45% no accident	§ 119	§ 140
§ 140	- § 32	**45% accident**	**§ 108**	**§ 60**
		55% no accident	§ 108	§ 140
§ 140	- § 45	**35% accident**	**§ 95**	**§ 60**
		65% no accident	§ 95	§ 140
§ 140	- § 60	**25% accident**	**§ 80**	**§ 60**
		75% no accident	§ 80	§ 140

In the following, you will be asked to answer three questions to check your understanding of the instructions.

Your Initial Endowment	Cost of Care	Prob% Collision	Your Final Earning	The Other Participant's Earning
§ 140	- § 0	**85% accident**	**§ 140**	**§ 60**
		15% no accident	§ 140	§ 140
§ 140	- § 5	**75% accident**	**§ 135**	**§ 60**
		25% no accident	§ 135	§ 140
§ 140	- § 12	**65% accident**	**§ 128**	**§ 60**
		35% no accident	§ 128	§ 140
§ 140	- § 21	**55% accident**	**§ 119**	**§ 60**
		45% no accident	§ 119	§ 140
§ 140	- § 32	**45% accident**	**§ 108**	**§ 60**
		55% no accident	§ 108	§ 140
§ 140	- § 45	**35% accident**	**§ 95**	**§ 60**
		65% no accident	§ 95	§ 140
§ 140	- § 60	**25% accident**	**§ 80**	**§ 60**
		75% no accident	§ 80	§ 140

1. Assume that you have invested 21 points in precautions. What is the correspondent probability of collision?
   - 75%
   - 45%
   - 55%
   - 25%
2. Assume that you have invested 12 points in precautions and that the collision happens. What is the final earning for you and for the other participant?
   - You: §95; Other participant: §60
   - You: §108; Other participant: §60
   - You: §128; Other participant: §60
   - You: §128; Other participant: §140
3. If the accident happens, you have always to compensate the other participant for the economic damage you caused to his/her car.
   - True
   - False

Please answer the question below. Your final earning and the final earning of the other participant will be computed based on your choice.

Your Initial Endowment	Cost of Care	Prob% Collision %	Your Final Earning	The Other Participant's Earning
§ 140	- § 0	**85% accident**	**§ 140**	**§ 60**
		15% no accident	§ 140	§ 140
§ 140	- § 5	**75% accident**	**§ 135**	**§ 60**
		25% no accident	§ 135	§ 140
§ 140	- § 12	**65% accident**	**§ 128**	**§ 60**
		35% no accident	§ 128	§ 140
§ 140	- § 21	**55% accident**	**§ 119**	**§ 60**
		45% no accident	§ 119	§ 140
§ 140	- § 32	**45% accident**	**§ 108**	**§ 60**
		55% no accident	§ 108	§ 140
§ 140	- § 45	**35% accident**	**§ 95**	**§ 60**
		65% no accident	§ 95	§ 140
§ 140	- § 60	**25% accident**	**§ 80**	**§ 60**
		75% no accident	§ 80	§ 140

Based on the table above, how much would you like to spend in precaution to avoid causing a damage to the other participant's car?

- § 0
- § 5
- § 12
- § 21
- § 32
- § 45
- § 60

Scenario 2

Consider now that **you have always to compensate the other participant** for the economic damage to his/her car. The other participant cannot take any precaution to avoid the collision. You can decide how much to spend in precautions.

- Please look at the first row of the table, you can decide to spend zero points in precautions.
  - If the collision does not happen (probability 15%), you get the initial earning (§140) and do not suffer any cost.
  - If the collision happens (probability 85%), you have to compensate the other participant for the damage caused to his/her car, so you get 140 - 80 = §60.
- Look at the second row of the table, investing 5 points in precautions reduces the probability of collision to 75%.
  - If the collision does not happen (probability 25%), you get the initial earning minus the cost of care, 140 - 5 = §135.
  - If the collision happens (probability 75%), you have to compensate the other participant for the damage caused to his/her car, so you get 140 - 5 - 80 = §55.
- Look at the bottom row of the table, investing 60 points reduces the probability of collision to 25%.
  - If the collision does not happen (probability 75%), you get the initial earning minus the cost of care, 140 - 60 = §80.
  - If the collision happens (probability 25%), you have to compensate the other participant for the damage caused to his/her car, so you get 140 - 60 - 80 = §0.

Cost of Care	Prob% <u>No Collision</u>	Your Final Earning <u>No Collision</u>	Prob% <u>Collision</u>	Your Final Earning <u>Collision</u>
§ 0	**15%**	§ 140	**85%**	§ 60
§ 5	**25%**	§ 135	**75%**	§ 55
§ 12	**35%**	§ 128	**65%**	§ 48
§ 21	**45%**	§ 119	**55%**	§ 39
§ 32	**55%**	§ 108	**45%**	§ 28
§ 45	**65%**	§ 95	**35%**	§ 15
§ 60	**75%**	§ 80	**25%**	§ 0

If an accident happens, you will always have to compensate the other participant, that is, you always bear the damage of §80.

Whether the accident happens or not, thanks to your compensation the other participant will always receive §140.

Let consider the following example. Imagine that you decide to invest 5 points in precautions:

- The probability of a collision is 75%;
- If the accident happens, your final earning will be 140 [initial points] - 5 [cost of precautions] - 80 [compensation for damages] = §55;
- If the accident does not happen, your final earning will be 140 [initial points] - 5 [cost of precautions] = §135;
- Whether the accident happen or not, the other participant will always earn §140 [initial points] since he/she will always receive compensation in case of an accident.

Your Initial Endowment	Cost of Care	Prob% Collision %	Your Final Earning	The Other Participant's Earning
§ 140	- § 0	**85% accident**	**§ 60**	**§ 140**
		15% no accident	§ 140	§ 140
§ 140	- § 5	**75% accident**	**§ 55**	**§ 140**
		25% no accident	§ 135	§ 140
§ 140	- § 12	**65% accident**	**§ 48**	**§ 140**
		35% no accident	§ 128	§ 140
§ 140	- § 21	**55% accident**	**§ 39**	**§ 140**
		45% no accident	§ 119	§ 140
§ 140	- § 32	**45% accident**	**§ 28**	**§ 140**
		55% no accident	§ 108	§ 140
§ 140	- § 45	**35% accident**	**§ 15**	**§ 140**
		65% no accident	§ 95	§ 140
§ 140	- § 60	**25% accident**	**§ 0**	**§ 140**
		75% no accident	§ 80	§ 140

In the following, you will be asked to answer three questions to check your understanding of the instructions.

Your Initial Endowment	Cost of Care	Prob% Collision %	Your Final Earning	The Other Participant's Earning
§ 140	- § 0	**85% accident**	**§ 60**	**§ 140**
		15% no accident	§ 140	§ 140
§ 140	- § 5	**75% accident**	**§ 55**	**§ 140**
		25% no accident	§ 135	§ 140
§ 140	- § 12	**65% accident**	**§ 48**	**§ 140**
		35% no accident	§ 128	§ 140
§ 140	- § 21	**55% accident**	**§ 39**	**§ 140**
		45% no accident	§ 119	§ 140
§ 140	- § 32	**45% accident**	**§ 28**	**§ 140**
		55% no accident	§ 108	§ 140
§ 140	- § 45	**35% accident**	**§ 15**	**§ 140**
		65% no accident	§ 95	§ 140
§ 140	- § 60	**25% accident**	**§ 0**	**§ 140**
		75% no accident	§ 80	§ 140

1. Assume that you have invested 12 points in precautions and that the collision does not happen. What is the final earning for you and for the other participant?

- You: §140 ; Other Participant: §48
- You: §140 ; Other Participant: §128
- You: §48 ; Other Participant: §140
- You: §128 ; Other Participant: §140

2. Assume that you have invested 12 points in precautions and that the collision happens. What is the final earning for you and for the other participant?

   - You: §95 ; Other Participant: §140
   - You: §108 ; Other Participant: §60
   - You: §48 ; Other Participant: §140
   - You: §48 ; Other Participant: §60

3. If the accident happens, you have always to compensate the other participant for the economic damage you caused to his/her car.

   - True
   - False

Please answer the question below. Your final earning and the final earning of the other participant will be computed based on your choice.

Your Initial Endowment	Cost of Care	Prob% Collision	Your Final Earning	The Other Participant's Earning
§ 140	- § 0	**85% accident**	**§ 60**	**§ 140**
		15% no accident	§ 140	§ 140
§ 140	- § 5	**75% accident**	**§ 55**	**§ 140**
		25% no accident	§ 135	§ 140
§ 140	- § 12	**65% accident**	**§ 48**	**§ 140**
		35% no accident	§ 128	§ 140
§ 140	- § 21	**55% accident**	**§ 39**	**§ 140**
		45% no accident	§ 119	§ 140
§ 140	- § 32	**45% accident**	**§ 28**	**§ 140**
		55% no accident	§ 108	§ 140
§ 140	- § 45	**35% accident**	**§ 15**	**§ 140**
		65% no accident	§ 95	§ 140
§ 140	- § 60	**25% accident**	**§ 0**	**§ 140**
		75% no accident	§ 80	§ 140

How much would you like to spend in precaution to avoid causing an economic damage to the other participant's car and then paying compensation?

- §0
- §5
- §12
- §21
- §32
- §45
- §60

5.7.2 Instructions for Victims

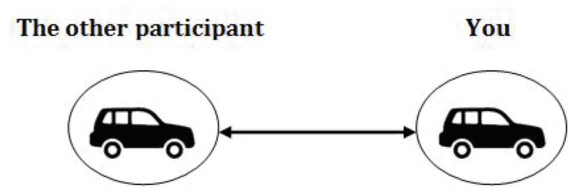
A short study on decision making

We are conducting a survey about care choices. The time needed to complete this survey is approximately 30 minutes. **Please read the instructions carefully**.

Imagine that you have an **initial portfolio of 140 points**. Your choices in the survey and chance will influence your final portfolio and also the final portfolio of another participant. For your participation in this study, you will receive extra-points for the final grade of the course exam.

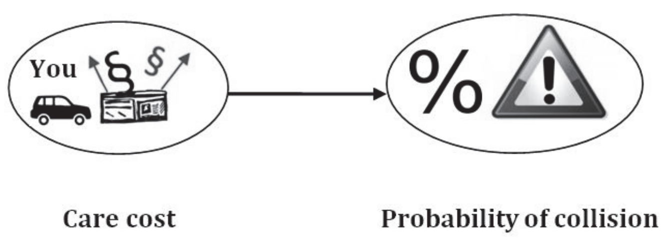
You are randomly **matched with another participant**, whose identity will remain private information.

Both you and the other participant have been assigned the role of drivers.



Your task is to decide **how much you want to invest in precautions to avoid a collision with the other participant's car causing an economic damage to your car**.

The more precautions you take, the higher the cost for you, but the lower the probability of suffering a damage to your car.



The other participant cannot take any precaution to avoid the collision.

Scenario 1

If the accident happens, **you will always receive compensation for the damage from the other participant**. In other words, in case of a collision, your car is damaged but the other participant who caused the accident will compensate you for the entire amount of the damage.

You can decide how many points you want to spend in precautions.

- Please look at the first row of the table corresponding to zero points in precautions. In this case you get the initial earning (§140) and do not suffer any cost of care. If you invest zero in precautions, the collision happens with a 85% probability.
- Look at the second row, investing 5 points in precautions reduces the probability of collision to 75%, and your final earning will be 140 - 5 = §135.
- Look at the bottom row of the table, investing 60 points reduces the probability of collision to 25%, and your final earning will be 140 - 60 = §80.

Cost of Care 	Your Final Earning 	Prob% Collision 
§ 0	§ 140	85%
§ 5	§ 135	75%
§ 12	§ 128	65%
§ 21	§ 119	55%
§ 32	§ 108	45%
§ 45	§ 95	35%
§ 60	§ 80	25%

The economic damage to your car in case of collision amount to §80.

If an accident happens, the other participant will pay for the damage he/she caused to your car and you will receive perfect compensation.

If the accident happens, the other participant's final payment will be 140 - 80 = §60.

If the accident does not happen, the other participant's final payment will be §140.

Let consider the following example. Imagine that you decide to invest 5 points in precautions:

- The probability of a collision is 75%;
- Whether the accident happen or not, your final earning will be 140 [initial points] - 5 [cost of precautions] = §135 since you always receive compensation from the other participant;
- The other participant will earn §140 [initial earning points] if the accident does not happen, or 140 - 80 [accident cost] = §60 if the accident happens since he will always pay to compensate the damages to your car.

Your Initial Endowment	Cost of Care	Prob% Collision %	Your Final Earning	The Other Participant's Earning
§ 140	- § 0	**85% accident**	**§ 140**	**§ 60**
		15% no accident	§ 140	§ 140
§ 140	- § 5	**75% accident**	**§ 135**	**§ 60**
		25% no accident	§ 135	§ 140
§ 140	- § 12	**65% accident**	**§ 128**	**§ 60**
		35% no accident	§ 128	§ 140
§ 140	- § 21	**55% accident**	**§ 119**	**§ 60**
		45% no accident	§ 119	§ 140
§ 140	- § 32	**45% accident**	**§ 108**	**§ 60**
		55% no accident	§ 108	§ 140
§ 140	- § 45	**35% accident**	**§ 95**	**§ 60**
		65% no accident	§ 95	§ 140
§ 140	- § 60	**25% accident**	**§ 80**	**§ 60**
		75% no accident	§ 80	§ 140

In the following, you will be asked to answer three questions to check your understanding of the instructions.

Your Initial Endowment	Cost of Care	Prob% Collision	Your Final Earning	The Other Participant's Earning
§ 140	- § 0	**85% accident**	**§ 140**	**§ 60**
		15% no accident	§ 140	§ 140
§ 140	- § 5	**75% accident**	**§ 135**	**§ 60**
		25% no accident	§ 135	§ 140
§ 140	- § 12	**65% accident**	**§ 128**	**§ 60**
		35% no accident	§ 128	§ 140
§ 140	- § 21	**55% accident**	**§ 119**	**§ 60**
		45% no accident	§ 119	§ 140
§ 140	- § 32	**45% accident**	**§ 108**	**§ 60**
		55% no accident	§ 108	§ 140
§ 140	- § 45	**35% accident**	**§ 95**	**§ 60**
		65% no accident	§ 95	§ 140
§ 140	- § 60	**25% accident**	**§ 80**	**§ 60**
		75% no accident	§ 80	§ 140

1. Assume that you have invested 21 points in precautions. What is the correspondent probability of collision?
   - 75%
   - 45%
   - 55%
   - 25%
2. Assume that you have invested 12 points in precautions and that the collision happens. What is the final earning for you and for the other participant?
   - You: §95 ; Other participant: §60
   - You: §108 ; Other participant: §60
   - You: §128 ; Other participant: §60
   - You: §128 ; Other participant: §140
3. If the accident happens, you have always receive compensation from the other participant for the economic damage to your car.
   - True
   - False

In the following you will be asked to answer the first question based on which your earning and the one of the other participant will be computed.

Your Initial Endowment	Cost of Care	Prob% Collision	Your Final Earning	The Other Participant's Earning
§ 140	- § 0	**85% accident**	**§ 140**	**§ 60**
		15% no accident	§ 140	§ 140
§ 140	- § 5	**75% accident**	**§ 135**	**§ 60**
		25% no accident	§ 135	§ 140
§ 140	- § 12	**65% accident**	**§ 128**	**§ 60**
		35% no accident	§ 128	§ 140
§ 140	- § 21	**55% accident**	**§ 119**	**§ 60**
		45% no accident	§ 119	§ 140
§ 140	- § 32	**45% accident**	**§ 108**	**§ 60**
		55% no accident	§ 108	§ 140
§ 140	- § 45	**35% accident**	**§ 95**	**§ 60**
		65% no accident	§ 95	§ 140
§ 140	- § 60	**25% accident**	**§ 80**	**§ 60**
		75% no accident	§ 80	§ 140

How much would you like to spend in precaution to avoid the collision and the damage to your car?

- §0
- §5
- §12
- §21
- §32
- §45
- §60

Scenario 2

Consider now that **you never receive compensation for the economic damage to your car**.

The other participant cannot take any precaution to avoid the collision. You can decide how many points you want to spend in precautions.

- Please look at the first row of the table, you can decide to spend zero points in precautions.
  - If the collision does not happen (probability 15%), you get the initial earning (§140) and do not suffer any cost.
  - If the collision happens (probability 85%), you suffer the accident loss of 80 without receiving any compensation. Your final earning will be 140 - 80 = §60.
- Look at the second row of the table, investing 5 points in precautions reduces the probability of collision to 75%.
  - If the collision does not happen (probability 25%), you get the initial earning minus the cost of care, 140 - 5 = §135.
  - If the collision happens (probability 75%), you suffer the accident loss of 80 without receiving any compensation. Your final earning will be 140 - 80 = §60.
- Look at the bottom row of the table, investing 60 points reduces the probability of collision to 25%.
  - If the collision does not happen (probability 75%), you get the initial earning minus the cost of care, 140 - 60 = §80.
  - If the collision happens (probability 25%), you suffer the accident loss of 80 without receiving any compensation. Your final earning will be 140 - 60 - 80 = §0.

Cost of Care 	Prob% <u>No Collision</u>	Your Final Earning <u>No Collision</u> 	Prob% <u>Collision</u>	Your Final Earning <u>Collision</u> 
§ 0	**15%**	§ 140	**85%**	§ 60
§ 5	**25%**	§ 135	**75%**	§ 55
§ 12	**35%**	§ 128	**65%**	§ 48
§ 21	**45%**	§ 119	**55%**	§ 39
§ 32	**55%**	§ 108	**45%**	§ 28
§ 45	**65%**	§ 95	**35%**	§ 15
§ 60	**75%**	§ 80	**25%**	§ 0

If an accident happens, you will never receive compensation for the damage that the other participant caused to your car, that is you always pay §80 to recover your damage.

Whether the accident happens or not, the other participant will always get §140.

Let consider the following example. Imagine that you decide to invest 5 points in precautions:

- The probability of a collision is 75%;
- If the accident happens, your final earning will be 140 [initial points] - 5 [cost of precautions] - 80 [cost of damages] = §55;
- If the accident does not happen, your final earning will be 140 [initial points] - 5 [cost of precautions] = §135;
- Whether the accident happen or not, the other participant will always earn §140 [initial points] since he/she will never pay compensation for the damages he/she caused.

Your Initial Endowment	Cost of Care	Prob% Collision	Your Final Earning	The Other Participant's Earning
§ 140	- § 0	**85% accident**	**§ 60**	**§ 140**
		15% no accident	§ 140	§ 140
§ 140	- § 5	**75% accident**	**§ 55**	**§ 140**
		25% no accident	§ 135	§ 140
§ 140	- § 12	**65% accident**	**§ 48**	**§ 140**
		35% no accident	§ 128	§ 140
§ 140	- § 21	**55% accident**	**§ 39**	**§ 140**
		45% no accident	§ 119	§ 140
§ 140	- § 32	**45% accident**	**§ 28**	**§ 140**
		55% no accident	§ 108	§ 140
§ 140	- § 45	**35% accident**	**§ 15**	**§ 140**
		65% no accident	§ 95	§ 140
§ 140	- § 60	**25% accident**	**§ 0**	**§ 140**
		75% no accident	§ 80	§ 140

In the following, you will be asked to answer three questions to check your understanding of the instructions.

1. Assume that you have invested 21 points in precautions and that the collision does not happen. What is the final earning for you and for the other participant?
   - You: §95 ; Other Participant: §140
   - You: §119 ; Other Participant: §140
   - You: §39 ; Other Participant: §140
   - You: §140 ; Other Participant: §39
2. Assume that you have invested 12 points in precautions and that the collision happens. What is the final earning for you and for the other participant?
   - You: §95 ; Other Participant: §140
   - You: §108 ; Other Participant: §60
   - You: §48 ; Other Participant: §140
   - You: §48 ; Other Participant: §60
3. If the accident happens, you have always receive compensation from the other participant for the economic damage to your car.

- True
- False

Your Initial Endowment	Cost of Care	Prob% Collision	Your Final Earning	The Other Participant's Earning
§ 140	- § 0	**85% accident**	**§ 60**	**§ 140**
		15% no accident	§ 140	§ 140
§ 140	- § 5	**75% accident**	**§ 55**	**§ 140**
		25% no accident	§ 135	§ 140
§ 140	- § 12	**65% accident**	**§ 48**	**§ 140**
		35% no accident	§ 128	§ 140
§ 140	- § 21	**55% accident**	**§ 39**	**§ 140**
		45% no accident	§ 119	§ 140
§ 140	- § 32	**45% accident**	**§ 28**	**§ 140**
		55% no accident	§ 108	§ 140
§ 140	- § 45	**35% accident**	**§ 15**	**§ 140**
		65% no accident	§ 95	§ 140
§ 140	- § 60	**25% accident**	**§ 0**	**§ 140**
		75% no accident	§ 80	§ 140

In the following you will be asked to answer the second question based on which your earning and the one of the other participant will be computed.

Your Initial Endowment	Cost of Care	Prob% Collision	Your Final Earning	The Other Participant's Earning
§ 140	- § 0	**85% accident**	**§ 60**	**§ 140**
		15% no accident	§ 140	§ 140
§ 140	- § 5	**75% accident**	**§ 55**	**§ 140**
		25% no accident	§ 135	§ 140
§ 140	- § 12	**65% accident**	**§ 48**	**§ 140**
		35% no accident	§ 128	§ 140
§ 140	- § 21	**55% accident**	**§ 39**	**§ 140**
		45% no accident	§ 119	§ 140
§ 140	- § 32	**45% accident**	**§ 28**	**§ 140**
		55% no accident	§ 108	§ 140
§ 140	- § 45	**35% accident**	**§ 15**	**§ 140**
		65% no accident	§ 95	§ 140
§ 140	- § 60	**25% accident**	**§ 0**	**§ 140**
		75% no accident	§ 80	§ 140

How much would you like to spend in precaution to avoid economic damages to your car?

- §0
- §5
- §12
- §21
- §32
- §45
- §60

6. Conclusion

The literature on the economic analysis of tort law is extensive and the precautionary streams generated by liability systems have been studied from different angles and perspectives. The economic analysis of law involves applying existing economic theories to legal contexts to identify the effects of legal rules on individual behaviors and whether these effects are socially desirable (Polinsky and Shavell, 2008; Calabresi, 2014). My analysis has focused on several characteristics of the incentive schemes created by the legal system through tort law. My task in this research has been to explore some overlooked issues about the incentive streams generated by alternative liability systems in different legal contexts. My general aim is twofold: to contribute to the development of more sophisticated models of tort law and to show that there remain many interesting unanswered questions despite the exhaustive literature on tort law and economics. My approach has been mainly theoretical, with an experimental application. As with any other research of this type, the translation of my theoretical and experimental results into practical guidelines for policy-makers has to take into account the intrinsic boundaries and the assumptions of the adopted frameworks. In the light of the methodology that I have used to answer my research questions, my results can be exploited to provide valuable policy implications.

This concluding chapter is divided into three parts: Section 6.1 summarizes the main results for each chapter, highlights the implications for policy-makers and provides several insights for future research. Section 6.2 discusses how the results achieved in the separate chapters may combine with each-other.

6.1 Main Results and Insights for Future Research

6.1.1 Endogenous Allocation of Residual Liability

Chapter 2 discusses how residual liability should be optimally allocated to foster superior (second-best) activity levels. The traditional analysis of accident law considers the allocation of the residual liability as an exogenous variable: the reason why the residual loss should fall on either the victim or the tortfeasor has been taken as given and has never been questioned. Chapter 2 identifies the conditions under which loss-sharing rules should be employed rather than conventional all-or-nothing based rules. The results show that loss-sharing rules among faultless parties are more desirable than all-or-nothing based rules in the presence of countervailing considerations on parties' activities (e.g., the activity of one individual is socially more valuable yet riskier than the other party's activity), homogeneous conditions of risk (e.g., similar riskiness of parties' activities, similar degree of parties' risk aversion) and superadditive risk (i.e., when moderate activity levels are less harmful than a high activity level of only one of the two parties). In the following, I will briefly discuss each of these conditions.

The reason why loss-sharing rules are desirable under homogeneous conditions of risk is intuitive. For example, let us consider the riskiness of activities. Intuitively, if the activity of the injurer is more likely to increase the probability of an accident with respect to the victim's activity, it is preferable to shift a larger portion of the residual loss onto the tortfeasor. When the injurer's activity is substantially riskier, the adoption of a strict-liability rule may be thus warranted. By contrast, when the victim's activity is riskier than that of the injurer, a negligence rule is more desirable. When the injurer' and the victim's activities have a similar degree of riskiness, the residual loss should be optimally shared among the two parties. A similar analysis applies to the value of activities, whereby residual liability should fall on the party that can reduce its activity level at a lower social cost. A reduction in the level of activity yields a reduction in the probability of an accident, as well as a decrease in the total value of the activity. For this reason, residual liability should be shifted upon the individual who undertakes the less valuable activity, because a reduction in the activity level will be less costly from a social perspective. It follows straightforwardly that when the parties' activities have comparable values, loss-sharing rules are preferable to all-or-nothing allocations.

To illustrate why loss-sharing rules are desirable in the presence of countervailing considerations on parties' activities, consider a collision between a car and a truck. Consider the case in which the truck driver's activity is socially more valuable yet creates a greater risk than the car. In this case, when considering the value of the activities, efficiency would require the application of a negligence rule. By contrast, when considering the riskiness of the activities, efficiency would instead require the application of a strict liability rule. In such cases in which efficiency criteria point in opposite directions, loss-sharing rules optimally balance the two countervailing policy objectives.

To illustrate why loss-sharing rules are desirable in the presence of superadditive risk, consider — for example — the emission of chemicals and noise in the environment. The presence of moderate quantities of the two pollutants may be less harmful than the presence of high levels of only one pollutant. In this situation, it is optimal to spread activity-level incentives between the parties through loss-sharing rules. By contrast, in the presence of subadditive risk, the total harm is greater when both parties carry out moderate activity levels conjunctly rather than when only one party exerts excessive activity levels. For example consider the presence of children and cyclists on a trail. The frequency of accidents grows larger as the two activities mix together, whereby having all children or all cyclists is preferable than having the two activities mixed together. In this situation, it would be optimal to separate complementary activities through regulation (e.g., planning pedestrian areas) or tort law by allocating the residual liability entirely on one party or the other through all-or-nothing based rules.

The findings presented in Chapter 2 further explain long-standing principles of the tort system, in addition to providing ways of improving them. For example, the results show that the party who carries out the riskier activity should bear the residual liability for non-negligent conduct. This can explain the widespread adoption of strict-liability rules in case of ultrahazardous activities, as well as the use of no-liability when the victim came to the nuisance or exposed herself to risk. Similarly, our analysis explains the presence of immunities or heightened standards of liability (gross negligence or intent required for liability) when socially valuable activities are involved.

As a final note, it should be noted that policy-makers' ability to effectively separate individuals based upon the characteristics of their activities might be compromised given the difficulty in measuring some of the factors involved (e.g., comparing the values of parties' activities). In cases where useful information is not known to the judicial system, loss-sharing rules provide a practical alternative to rules in which only one party bears the entire accident costs.

Chapter 2 analyzes who should optimally bear the residual loss to generate optimal activity-level incentives. The identification of the "best residual-liability-bearer" could be refined by evaluating the relevance of other factors. For example, future studies can analyze how to allocate the residual loss when one of the two parties can take precautions most cheaply (the cheapest precaution taker) or most effectively (the most effective precaution taker). Further investigations could also study all the policy instruments that can be used to influence activity levels. There might be situations in which it is optimal to use the allocation of residual liability to mitigate activity levels, as well as others in which it is more desirable to set different due-care standards, and further situations in which due-care standards and residual liability both play a crucial role for activity-level incentives.

6.1.2 Tailoring Negligence Standards to Automation

Chapter 3 extends the standard unilateral-care tort model to analyze the social cost of accidents in cases where the actor is not a human being, but rather an automated technology. The general question is whether conventional negligence-based liability systems should change to encourage the production and adoption of new automated technologies. The analysis leads to two fundamental results, the first of which is related to care-level incentives. More specifically, Chapter 3 has proved that the standard of due-care should be optimally tailored to the automation level of the activity, i.e., it should decrease with increasing automation. It follows that as the activity tends towards full automation, a negligence regime gradually degenerates into a no-liability rule. In other words, the traditional concept of the reasonable person standard used to evaluate a negligent behavior should slightly change to consider the level of activity automation. This result is intuitive and coherent with the recent contribution by Dari-Mattiacci and Franzoni (2014), who argued that "if the new technology reduces harm substantially, adoption should be encouraged: court should relax the standard of the new technology and raise that of the old one." For example, the case of autonomous vehicles brings this claim to an extreme, whereby this technology has the potential to substantially increase social welfare by reducing the probability of accidents, and — to encourage their adoption — the due-care standard for users of driverless vehicles should be substantially reduced, while the due-care standards for users of similar non-automated products should be raised. This latter observation could be included in

Chapter 3, whereby an interesting extension of my theoretical framework could be to explore how the negligence standards should change when parties involved in an accident adopted different types of technologies.

This result has also another implication concerning the potential benefits of automated technologies. If the users of automated technologies could be held liable for accidents that such technologies “caused,” they could have incentives either to always monitor the actions of the automated devices — thus nullifying the intrinsic function of automated products — or to not adopt safer automated devices to have a major control of the activity. Instead, tailored standards are aligned with the purposes of automated technologies, allowing the user to be distracted while automated devices perform an activity autonomously, without the threat of liability issues. Consequently, tailored due-care standards also create an incentive to adopt safer, automated technologies, especially for risky actions, as well as proving their actual usage in courts to avoid full liability costs.

The second result is related to activity-level incentives. Automatic technologies can trace the user’s activity and thus preserve information that can be eventually used by courts and juries to monitor the user’s activity level. The question arising is whether automated-activity levels that become observable should be included in the standard of negligence. The answer lies in the trade-off between creating incentives for socially optimal automated-activity levels and creating incentives to adopt automated technologies. More specifically, including activity levels in the negligence standard could create optimal incentives on activity levels, although it would reduce the incentives to adopt automated technologies in the first place. For this reason, the standard of negligence should also consider activity levels when the automated technology is already widely adopted or mandated by regulation.

Technological advances in the automation sector have the potential to change the liability system and the legal definition of negligence. Chapter 3 represents a first attempt to include automation into the traditional economic analysis of accident law. Several extensions of our model are warranted to test whether our results hold in different contexts, including asymmetric information between the consumer and the manufacturer, a bilateral accident model in which both injurers and victims can adopt different types of safety technologies, and automated technologies that are complements to the user's care level.

As a final note, it is worth stressing that the insurance system together with the liability system play a crucial role in creating a market for new automated technologies (see, more generally, Faure, 2006, on the conditions under which insurance should be made compulsory). Tort, product and insurance liability should be studied as an overall integrated system to better understand whether and how the traditional legal framework should change in line with the advent of new automated technologies. Several, mostly legal, contributions have studied the possible changes in the insurance system. For example, with respect to driverless cars, Colonna (2012) proposed a new insurance framework that could work in conjunction with the current tort law. Specifically, Colonna argued for the desirability a two-tiered insurance structure similar to the nuclear energy industry's Price-Anderson Act. This system requires each autonomous car and technology manufacturer to obtain a first tier private insurance policy and annually contribute to a second tier or pool of funds. Each manufacturers' contribution to the second pool of funds depends on the type of product they produce, their predicted revenue and the amount of risk that they expect to incur. Colonna argued that this system can alleviate the manufacturers' worries of uncertain liability, while imposing no costs on consumers nor governments.

Chapter 3 provides several insights for further investigations on automated technologies. For example, future research could question how to allocate liability costs when both parties involved in an accident exerted an automated activity (e.g., a collision between two driverless cars) or how a potential no-fault liability for automated technologies can be mitigated with an optimal allocation of the burden of proof. Indeed, the more these machines become interactive and autonomous, the more third parties will find it difficult to prove that the manufacturer or product-user did not conform to a certain standard of conduct. In these cases, questioning the traditional allocation of the burden of proof upon the plaintiffs appears to have a crucial importance. It would be also interesting to consider the administrative costs of tailoring due-care standards to automated technologies, as suggested in Chapter 3. It might be the case that even if the liability system does not change, the expected decrease in the number of crashes and the consequent reduction in insurance costs would nonetheless encourage people and insurance companies to adopt this technology. This solution would avoid the additional administrative costs of tailored due-care standards. The theoretical framework introduced in Chapter 3 could be used to evaluate these open questions.

6.1.3 Optimal Definition of Legal Presumptions

Chapter 4 uses a simple model to study the effects of legal presumptions in a tort setting. There are two key insights of this chapter: first, there is nothing fundamentally necessary about placing the burden of proof on plaintiffs; and second, legal presumptions channel individual behaviors by generating three incentive streams, i.e., incentives to invest in evidence-production technology, in care and activity levels. Chapter 4 proceeds stepwise by considering these three factors which could optimally guide the definition of legal presumptions.

New evidence technologies such as genetic testing, computer recording of data, black-box technology, body cameras and traffic surveillance cameras, are substantially increasing the amount of information that can be acquired, preserved, and used in court to support a claim. Chapter 4 points out that the incentives to adopt private fact-keeping technologies are endogenously determined by evidence law: if optimally defined, legal presumptions could create incentives for the voluntary adoption of such technologies. The result is very intuitive: a party who knows that he may be faced with the burden of proving his diligent behavior would develop an interest in adopting evidence technologies. By contrast, if the information gathered by such technologies could be used against its own user, the adoption incentives would obviously diminish. The first result follows in a straightforward manner from these simple observations: the party who is faced with the burden of proof has incentives to voluntary adopt evidence technologies. For this reason, the burden of proof should be shifted upon the party who can more effectively adopt such technologies.

In terms of the effects of legal presumptions on care levels, Chapter 4 shows that tort incentives react differently to changes in legal presumptions in the presence of discovery errors. The current literature has assumed away discovery errors, arguing that legal presumptions have no effect on care incentives (Hay and Spier, 1997). However, in real-life cases, parties would frequently have probatory difficulties. For example, consider the conventional allocation of the burden of proof under a simple negligence regime, whereby the victim has to prove the tortfeasor's negligence to receive harm compensation. In most cases, the probability that the victim will succeed in proving the tortfeasor's negligence is less than 1 (as it is instead assumed in the current literature on the definition of legal presumption – e.g., Hay and Spier, 1997). In other words, there is a positive probability that a tortfeasor could avoid liability notwithstanding his negligence. In the presence of such discovery errors, the tortfeasor will undertake optimal care if and only if the probability that the victim will fail to prove the defendant's negligence is sufficiently low, otherwise the tortfeasor's care incentives will be diluted. As probatory difficulties for the plaintiff increase, a simple negligence rule gradually degenerates into a no liability rule, completely undermining the defendant's care incentives. Chapter 4 shows that a shift of the legal presumption could mitigate this problem. Indeed, consider the same situation, albeit with a presumption of negligence on the tortfeasor: if the tortfeasor fails to produce evidence of his own diligence, he bears full liability. Unlike what is observed under a presumption of non-negligence on the tortfeasors, the negligence rule under a presumption of negligence on the tortfeasor degenerates into a strict liability rule as probatory difficulties for the defendant increase; thus, the tortfeasor's care incentives are preserved. A similar analysis has been applied to a regime of strict liability with contributory negligence. In conclusion, Chapter 4 shows that the optimal definition of legal presumption depends upon the relative probatory difficulties of the parties involved in a claim in order to preserve parties' precautionary choices.

Regarding the effects of legal presumptions on activity levels, Chapter 4 relies on simple observations to argue that the burden of proof — which works as a tax on activity levels — can lead either the residual bearer of the loss to exert levels below the social optimum, or the non-bearer of the residual loss to reduce his excessive levels. It is obvious that the second alternative is preferable to the former, whereby both parties' activity levels would approach the social optimum.

Chapter 4 aggregates the three forementioned interrelated effects of legal presumption into the best-discovery-bearer principle, which stands as an alternative to the traditional cheapest-evidence-producer criterion following which legal presumptions should be defined solely to minimize truth-finding costs. The best-discovery-bearer principle requires a shift of the burden of proof to the parties: (a) who can most effectively invest in evidence technology; (b) whose precautions are more inelastic relative to discovery errors (to preserve care incentives and guarantee the robustness of liability rules in the presence of adjudication errors); and (c) who are not already burdened by the residual liability (to mitigate excessive activity levels of both parties without pushing the activity level of the residual bearer below the socially optimal level).

Chapter 4 offers many insights for future research on the optimal allocation of the burden of proof. For example, how should the burden of proof be assigned if the factors included in the “best-discovery-bearer” point in different directions? For example, a party can have a low probability of making discovery errors but also be the residual bearer of the loss. How should the burden of proof be assigned if a party is the best discovery-bearer but not the cheapest evidence-producer? Intuitively, the answer to both these questions should depend on which factor prevails in pursuing two or more countervailing policy objectives. For example, consider a simple negligence regime in which a victim has to prove the tortfeasor’s negligence. Let us assume that the victim has a lower probability of making discovery errors than the tortfeasor. The efficiency criterion identified in Chapter 4 regarding care-level incentives would require the allocation of the burden of proof upon the victim. However, the third efficiency criterion related to the activity-level incentives would require a shift of the burden of proof upon the tortfeasor, given that he does not bear the residual liability. In this hypothetical situation, the efficiency criteria clearly point in opposite directions. If one of the two policy objectives prevails from a social perspective (i.e., from the perspective of minimizing expected accident costs), efficiency would require allocating the burden of proof in accordance with such a dominant objective. There might be situations in which neither of the two objectives prevail. In such cases, any choice between the two alternative definitions of legal presumptions would be optimal. In general and by intuition, when a trade-off arises between two or more policy objectives (e.g., incentivizing the adoption of evidence technology vs. preserving care incentives when discovery errors are present), the best-discovery-bearer principle would require defining legal presumptions according to the policy objective that prevails from a social perspective, or to indifferently follow one among the countervailing policy objectives if none of them prevails. These observations follow by intuition, and a more sophisticate analysis along this path is warranted.

Moreover, the theoretical framework presented in Chapter 4 can be fruitfully exploited in two ways: it can be generalized by also including victim's care levels; and it can be unified to study all the effects of legal presumptions on tort incentives conjunctively. A possible extension can consider a litigation model in which parties move sequentially.

6.1.4 Liability Incentives are Role-Dependent

The theoretical analysis of tort law predicts that liability incentives are role-independent: individuals undertake the same precautionary choices under mirrored liability rules (i.e., the rules of strict liability and no liability), regardless of them being victims or tortfeasors of an accident. Chapter 5 focuses on such a theoretical prediction by asking whether liability incentives are effectively role-independent. Conversely, do people undertake different precautionary behaviors depending upon them being victims or injurers of an accident? The rationale of this question comes from the growing literature in neuroscience, behavioral and experimental economics on other-regarding preferences. Several studies show that individuals care about the well-being of others, showing a willingness to sacrifice their own endowment to prevent harming others and to cooperate in social dilemmas (Eckel and Grossman, 1996,; Fehr and Fischbacher, 2004; Fehr and Schmidt, 2006; Henrich et al., 2010; Engel, 2011; Rand et al., 2012). Chapter 5 adds to this literature by evaluating prosocial behaviors in the context of accident prevention, by relying upon the theoretical predictions of the economic analysis of accident law.

The experimental results show that subjects are less likely to suffer a loss rather than to cause it. In other words, under mirrored liability rules (i.e., the rules of no liability and strict liability), victims have devoted more resources to preventing an accident than potential injurers, even under a full compensation of damages. This result stands in contrast with the theoretical predictions of the traditional tort model by showing that care incentives are role-dependent, while it also provides a new risky context in which to evaluate prosocial preferences.

The most surprising result is that in the "strict liability case," victims invest about as much as injurers. This is interesting because victims are perfectly insured. More specifically, in the "Victim StrictLiability" condition, injurers have to pay whenever damage occurs, although only victims can do anything about this. I would interpret this result as another instance of social preferences, whereby the victims see it as unfair to make the injurers lose money with such a high probability.

Future research could analyze whether the result in Chapter 5 holds true under different conditions. The first two obvious extensions are to consider a lower probability range of accident and a bilateral-care model in which both parties can take actions to avoid a collision. Other extensions might also include the uncertainty of being victims or injurers in an accident, as well as the possibility that injurers also suffer a share of the loss together with the victims.

6.2 Concluding Remarks on the Main Results

Despite dealing with specific research questions, the separate chapters of my dissertation combine with each others in one or more aspects. This section briefly discusses the existence of possible balances between the different policy objectives separately identified in the previous chapters. The central interest throughout my dissertation lies with individual incentives to undertake different measures of precautions, namely care levels and precautionary technologies (Chapters 2, 3, 4 and 5) as well as activity levels (Chapters 2 and 3).

In terms of care-level incentives, Chapters 2 shows that under any fault-based liability regime, parties have incentives to comply with due-care standards if these latter are set at their second-best and regardless of the allocation of the loss among negligent parties. This claim might be refined by considering the results of the following chapters. If potential injurers have adopted automated technologies, care incentives are preserved under due-care standards tailored to automation (Chapter 3). Moreover, in the presence of large probatory difficulties, care incentives are undermined under the traditional definition of legal presumptions. If read together, the results from Chapters 3 and 4 suggest the desirability of the no liability rule with a shift of the burden of proof upon the tortfeasor when this latter adopts fully automated technologies (e.g., driverless cars). In fact, under due-care standards tailored to automation, the simple negligence rule gradually degenerates into the no liability rule as activity becomes fully automated (Chapter 3). At the same time, the more the tortfeasor's activity become autonomous, the more potential victims will find it difficult to prove that the manufacturer or the product-user did not conform to a certain standard of conduct. As proven in Chapter 4, in the presence of a victim's high probatory difficulties, the burden of proof should be shifted upon the tortfeasor to preserve their care incentives. In addition to tailored due-care standards, also this change in the definition of legal presumption is likely to foster the adoption of safer automated technologies. Indeed, if he has to prove his non-negligent behavior, a potential tortfeasor would have incentives to reduce the probability of an accident by investing in safer devices. Chapter 5 deals with care incentives as the other chapters in this book, with the aim to identify the actual precautionary behavior of the parties and compare it with the predicted theoretical behavior. Chapter 5 shows that victims are potentially more willing to undertake precautions than tortfeasors. This result has the potential to affect the allocation of the residual loss. Since victims are generally more careful than potential injurers, they will exert risky activities at a lower intensity or frequency than tortfeasors. This might suggest to shift a larger share of the residual loss upon potential tortfeasors, even when parties are identical, i.e., when the efficiency criteria described in Chapter 2 suggests an equal split of the residual loss.

Regarding activity-level incentives, Chapter 2 shows which party should bear the accident loss in equilibrium based upon the relevant characteristics of parties' activities and risk preferences. Chapter 4 also deals with residual liability, stating that legal presumptions should optimally favor the residual bearer of the loss, whereby the non-bearer of the residual loss also has incentives to reduce his excessive activity level. In the presence of loss-sharing rules among non-negligent parties, this result implies the burden of proof should be shifted upon the party who bears the lower share of the residual loss. Chapter 3 further states the desirability of a negligence standard based upon activity levels in the presence of widely adopted automated technologies. In general, the analyses in these three chapters suggest that an endogenous allocation of the residual liability, a selective use of the burden of proof and due levels of automated activities are valuable instruments that policy-makers can use to influence parties' activity levels. Furthermore, the results in Chapter 3 show that the due level of automated activity should optimally increase with the automation level. Since automated activities are less risky than non-automated activities, the results from Chapters 2 and 3 — if read together — imply that the party that has adopted a fully automated technology should face a low due-care standard and a due level of automated activity, as well as a lower share of the residual loss (as the efficiency criterion on the riskiness of activity would require; see Section 2.3.1 of Chapter 2). The definition of a due-activity level thus counterbalances the lower share of the residual liability. When considering that the optimal allocation of the burden of proof is upon the non-residual bearer of the loss, one could accordingly interpret Table 2 as defining not only who should bear the residual loss but also who should bear the burden of proof, i.e., the party that is not indicated in the cell of the table.

6.3 A Final Note

My analysis started from the premise that the economic analysis of accident law could be rendered more accurate by making its theoretical framework more sophisticated and in line with the recent behavioral findings. My impression is that much more could be done, especially in two directions: refining tort models to better predict human behavior and testing whether these theoretical predictions are more accurate in experimental and empirical studies. All of the chapters of my dissertation provide interesting ideas for future research and can be profitably exploited to investigate other issues in the economics of tort law and related fields.

7. English Summary

The analysis of tort law is one of the most influential and extensively developed applications of the economic approach in the study of law. Notwithstanding the exhaustive number of contributions on tort law and economics, several open questions remain that warrant further investigation. The general aim of this research project is to refine the traditional model of tort law in order to make it more realistic, updated with the recent technological progress and in line with the experimental results concerning prosocial behavior. This book is divided into six chapters: Chapters 1 and 6 provide an introduction and conclusions, respectively, while the remaining chapters are written in the form of separate yet related articles.

The first research topic deals with the optimal allocation of the residual liability to foster superior (second-best) activity-level incentives. The term "residual liability" denotes liability in cases where both injurer and victim have adopted the due standards of care (i.e., when both parties are non-negligent). The allocation of residual liability is a policy instrument for influencing activity-level incentives. Traditional tort regimes have adopted "all-or-nothing" approaches, whereby the residual liability is entirely allocated either to the tortfeasor or to the victim, with no possibility of loss sharing between non-negligent parties. The choice between conventional all-or-nothing rules and loss-sharing rules as alternative allocation of the residual liability accrues a crucial role in incentivizing optimal activity levels, but has never been questioned. Chapter 2 addresses this issue and proves that the allocation of the residual loss should optimally depend upon the relevant characteristics of parties' activities — e.g., riskiness, value, and interaction in the production of accident loss — and upon parties' relative risk attitudes. The results show that loss-sharing rules among faultless parties are more desirable than traditional all-or-nothing based rules in a large variety of situations, for example when parties' activities have the same value and degree of riskiness and when moderate activity levels are less harmful than a high activity level of only one of the two parties.

The allocation of residual liability is relevant not only for activity-level incentives, but also for investments in new precautionary technologies. Chapter 3 deals with a specific type of safer technologies, namely automated technologies, for example driverless cars and automated drones. The conventional economic conception of tort law has indeed assumed the existence of two human actors - a tortfeasor and a victim - although this assumption becomes tenuous with the recent advancements in the automation sector. The question arising in the presence of automated activities is whether and how the current negligence-based liability system should evolve to encourage such technologies. Chapter 3 shows that the traditional concept of the reasonable person standard, used to evaluate whether an actor was negligent, should slightly change to consider the level of activity automation and that the standard of due care should also include activity levels when the automated technology is already widely adopted or mandated by regulation.

Automated technologies have the potential to affect not only liability law and regulation, but also the law of evidence. Indeed, the more such machines become interactive and autonomous, the more third parties will find it difficult to prove that the manufacturer or the product user did not conform to a certain standard of conduct. In these cases, questioning the traditional allocation of the burden of proof upon the plaintiffs appears to hold crucial importance. Chapter 4 proceeds along this path by questioning the traditional allocation of the burden of proof in a tort setting. There are two main results: first, there is nothing fundamentally necessary about placing the burden of proof on plaintiffs, unlike the traditional evidence law would rather predict; and second, the allocation of legal presumptions channels individual behaviors by generating three incentive streams: incentives to invest in evidence-production technology, to undertake care measures in the presence of adjudication errors and to mitigate excessive activity levels. The results show that the burden of proof should be allocated to strengthen the robustness of incentives in the presence of evidentiary problems, and this requires a shift of the burden of proof to the parties (a) who can most effectively invest in evidence technology; (b) whose precautions are more critical for accident costs; and (c) who are not already burdened by the residual liability.

Chapter 5 deals with care incentives and aims at identifying the actual precautionary behavior of the parties, rather than the theoretical behavior, which was the focus of the other chapters. Chapter 5 aims at evaluating prosocial behaviors and other-regarding preferences in the context of accident prevention. The results show that individuals spend more resources to avoid suffering a loss themselves than to avoid causing a loss to another subject. This is a novel result which adds behavioral insights to the traditional economic analysis of accident law and to the extant contributions on prosocial behavior. Indeed, this observation stands in contrast with one of the acknowledged results on other-regarding preferences, being that individuals dislike being responsible of bad outcomes, especially when they affect others' well-being. The added cost of moral responsibility does not lead people to value others' losses more than their own in an accident situation. This study provides a novel context for further testing moral preferences and antisocial behaviors, with several implications for many legal and political decisions about social interactions in risky situations.

All chapters of this book provide interesting ideas for future research and can be profitably exploited to investigate other issues in the economics of tort law and related fields, especially in two directions: refining tort models to better predict human behavior and testing whether these theoretical predictions are more accurate in experimental and empirical studies.

References

Adler, M. and J. Michael (1931). *The Nature of Judicial Proof: An Inquiry into the Logical, Legal, and Empirical Aspects of the Law of Evidence*. Ad Press.

Akitsuki, Y. and J. Decety (2009). Social context and perceived agency affects empathy for pain: an event-related fmri investigation. *Neuroimage 47*(2), 722–734.

Angelova, V., O. Armantier, G. Attanasi, and Y. Hiriart (2013). Relative performance of liability rules: experimental evidence. *Theory and Decision*, 1–26.

Arlen, J. and E. Talley (2008). *Experimental Law and Economics*. Edward Elgar.

Arlen, J. H. (1992). Should defendants' wealth matter? *Journal of Legal Studies*, 413–429.

Avraham, R. (2015). Does the theory of insurance support awarding pain and suffering damages in torts? *Edward Elgar Research Handbook in the Law and Economics of Insurance (2015)*.

Bar-Gill, O. and O. Ben-Shahar (2003). The uneasy case for comparative negligence. *American Law and Economics Review 5*(2), 433–469.

Bardsley, N. (2008). Dictator game giving: Altruism or artefact? *Experimental Economics 11*(2), 122–133.

Batson, C. D., B. D. Duncan, P. Ackerman, T. Buckley, and K. Birch (1981). Is empathic emotion a source of altruistic motivation? *Journal of Personality and Social Psychology 40*(2), 290.

Baumann, F. and K. Heine (2013). Innovation, tort law, and competition. *Journal of Institutional and Theoretical Economics 169*(4), 703–719.

Ben-Shahar, O. (1998). Should products liability be based on hindsight? *Journal of Law, Economics and Organization 14*(2), 325–357.

Bernardo, A., E. L. Talley, and I. Welch (2000). A theory of legal presumptions. *Journal of Law, Economics and Organization 16*, 1–49.

Blair, R. J. R. (1995). A cognitive developmental approach to morality: Investigating the psychopath. *Cognition 57*(1), 1–29.

Brown, J. P. (1973). Toward an economic theory of liability. *Journal of Legal Studies*, 323–350.

Brownlie, I. (1990). *Principles of public international law*, Volume 66. Clarendon Press Oxford.

Calabresi, G. (1961). Some thoughts on risk distribution and the law of torts. *Yale Law Journal*, 499–553.

Calabresi, G. (1965). The decision for accidents: An approach to non-fault allocation of costs. *Harvard Law Review 78*, 713–745.

Calabresi, G. (1970). *The cost of accidents: A legal and economic analysis*. Yale University Press.

Calabresi, G. (1996). Address at the 6th Annual Meeting of the American Law and Economics Association. *Chicago, May, 10-11*.

Calabresi, G. (2014). Of tastes and values. *American Law and Economics Review 16*(2), 313–332.

Calabresi, G. and J. Cooper (1996). New directions in tort law. *Valparaiso University Law Review 30*, 859–884.

Calo, M. (2010). Open robotics. *Maryland Law Review 42*, 101–142.

Camerer, C. (2003). *Behavioral game theory: Experiments in strategic interaction*. Princeton University Press.

Camerer, C. and R. H. Thaler (1995). Anomalies: Ultimatums, dictators and manners. *Journal of Economic Perspectives*, 209–219.

Cardi, W. J., R. D. Penfield, and A. H. Yoon (2012). Does tort law deter individuals? A behavioral science study. *Journal of Empirical Legal Studies 9*(3), 567–603.

Charness, G. (2000). Responsibility and effort in an experimental labor market. *Journal of Economic Behavior & Organization 42*(3), 375–384.

Charness, G. and M. O. Jackson (2009). The role of responsibility in strategic risk-taking. *Journal of Economic Behavior & Organization 69*(3), 241–247.

Cheng, Y., C.-P. Lin, H.-L. Liu, Y.-Y. Hsu, K.-E. Lim, D. Hung, and J. Decety (2007). Expertise modulates the perception of pain in others. *Current Biology 17*(19), 1708–1713.

Cohen, M. A. and T. R. Miller (2003). Willingness to award nonmonetary damages and the implied value of life from jury awards. *International Review of Law and Economics 23*(2), 165–181.

Coleman, J. L. (1982). Moral theories of torts: Their scope and limits: Part I. *Law and Philosophy 1*(3), 371–390.

Coleman, J. L. (1991). Tort law and the demands of corrective justice. *Indiana Law Journal 67*, 349.

Colonna, K. (2012). Autonomous cars and tort liability. *Case Western Reserve Journal of Law, Technology and the Internet*.

Cooper, D. and J. H. Kagel (2009). Other regarding preferences: A selective survey of experimental results. *Handbook of experimental economics 2*.

Cooter, R. and T. Ulen (2007). *Law and economics*. Pearson Series in Economics.

Crockett, M. J., Z. Kurth-Nelson, J. Z. Siegel, P. Dayan, and R. J. Dolan (2014). Harm to others outweighs harm to self in moral decision making. *Proceedings of the National Academy of Sciences 111*(48), 17320–17325.

Dari-Mattiacci, G. (2005). On the optimal scope of negligence. *Review of Law and Economics 1*(3), 331–364.

Dari-Mattiacci, G. and G. De Geest (2005). The filtering effect of sharing rules. *Journal of Legal Studies 34*(1), 207–237.

Dari-Mattiacci, G. and L. A. Franzoni (2014). Innovative negligence rules. *American Law and Economics Review*.

Dari-Mattiacci, G., B. Lovat, and F. Parisi (2014). Loss-sharing between nonnegligent parties. *Journal of Institutional and Theoretical Economics*.

Dari-Mattiacci, G. and F. Parisi (2006). The economics of tort law: A precis. In J. G. Backhaus (Ed.), *The Elgar Companion to Law and Economics*. Edward Elgar Publishing.

Dari-Mattiacci, G. and F. Parisi (2013). Liability rules: An economic taxonomy. In M. Bussani and A. Sebok (Eds.), *Comparative Tort Law*. Cheltenham: Edward Elgar.

Daugherty, A. and J. Reinganum (2000). On the economics of trials: Adversarial process, evidence, and equilibrium bias. *Journal of Law, Economics and Organization 16*, 365–394.

De Dreu, C. K., L. L. Greer, M. J. Handgraaf, S. Shalvi, G. A. Van Kleef, M. Baas, F. S. Ten Velden, E. Van Dijk, and S. W. Feith (2010). The neuropeptide oxytocin regulates parochial altruism in intergroup conflict among humans. *Science 328*(5984), 1408–1411.

De Geest, G. and B. Bouckaert (1992). *Bibliography of law and economics*. Kluwer.

De Geest, G. and B. Bouckaert (2000). *Encyclopedia of Law and Economics*. E. Elgar.

De Mot, J. and B. Depoorter (2011). Technology and torts: Memory costs, nondurable precautions and interference effects. *International Review of Law and Economics*.

De Ville, K. (1998). Medical malpractice in twentieth century united states: The interaction of technology, law, and culture. *International Journal of Technology Assessment in Health Care 14*(02), 196–211.

DeJoy, D. M. (1989). The optimism bias and traffic accident risk perception. *Accident Analysis and Prevention 21*(4), 333–340.

Dewees, D. N., D. Duff, M. J. Trebilcock, D. Duff, and M. J. Trebilcock (1996). *Exploring the domain of accident law: Taking the facts seriously*. Oxford University Press Oxford.

Diamond, P. A. (1974). Single activity accidents. *Journal of Legal Studies*, 107–164.

Eckel, C. C. and P. J. Grossman (1996). Altruism in anonymous dictator games. *Games and Economic Behavior 16*(2), 181–191.

Edlin, A. S. and P. K. Mandic (2006). The accident externality from driving. *Journal of Political Economy 114*(5), 931–955.

Eisenberg, T. and C. Engel (2012). Assuring adequate deterrence in tort: A public good experiment. *MPI Collective Goods Preprint* (2012/7), 12–27.

Emons, W. (1990a). Efficient liability rules for an economy with non-identical individuals. *Journal of Public Economics 42*(1), 89–104.

Emons, W. (1990b). Some recent developments in the economic analysis of liability law: An introduction. *Journal of Institutional and Theoretical Economics*, 237–248.

Emons, W. and J. Sobel (1991). On the effectiveness of liability rules when agents are not identical. *Review of Economic Studies 58*(2), 375–390.

Endres, A. and R. Bertram (2006). The development of care technology under liability law. *International Review of Law and Economics 26*(4), 503–518.

Endres, A. and T. Friehe (2011a). Incentives to diffuse advanced abatement technology under environmental liability law. *Journal of Environmental Economics and Management 62*(1), 30–40.

Endres, A. and T. Friehe (2011b). The reasonable person standard: Trading off static and dynamic efficiency. *European Journal of Law and Economics*, 1–19.

Endres, A. and T. Friehe (2012). Generalized progress of abatement technology: Incentives under environmental liability law. *Environmental and Resource Economics 53*(1), 61–71.

Endres, A. and T. Friehe (2013). Led on the wrong track? A note on the direction of technical change under environmental liability law. *Journal of Public Economic Theory 15*(3), 506–518.

Endres, A., B. Rundshagen, and R. Bertram (2008). Environmental liability law and induced technical change: The role of spillovers. *Journal of Institutional and Theoretical Economics*, 254–279.

Engel, C. (2011). Dictator games: A meta study. *Experimental Economics 14*(4), 583–610.

Fagnant, D. and K. Kockelman (2013). Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations. *ENO Center for Transportation*.

Faure, M. (2009a). *Tort law and economics*. Encyclopedia of Law and Economics, Edward Elgar Publishing.

Faure, M. G. (2000). Product liability and product safety in europe: Harmonization or differentitation. *Kyklos 53*(4), 467–508.

Faure, M. G. (2006). Economic criteria for compulsory insurance. *The Geneva Papers on Risk and Insurance-Issues and Practice 31*(1), 149–168.

Faure, M. G. (2009b). Environmental liability. In M. G. Faure (Ed.), *Tort Law and Economics*. Edward Elgar.

Fehr, E. and U. Fischbacher (2003). The nature of human altruism. *Nature 425*(6960), 785–791.

Fehr, E. and U. Fischbacher (2004). Social norms and human cooperation. *Trends in cognitive sciences 8*(4), 185–190.

Fehr, E. and K. M. Schmidt (2006). The economics of fairness, reciprocity and altruism: Experimental evidence and new theories. *Handbook of the economics of giving, altruism and reciprocity 1*, 615–691.

Fong, C. M. (2007). Evidence from an experiment on charity to welfare recipients: Reciprocity, altruism and the empathic responsiveness hypothesis. *Economic Journal 117*(522), 1008–1024.

Forsythe, R., J. L. Horowitz, N. E. Savin, and M. Sefton (1994). Fairness in simple bargaining experiments. *Games and Economic Behavior 6*(3), 347–369.

Ganuza, J.-J. and F. Gomez (2005). Caution, children crossing: Heterogeneity of victim's cost of care and the negligence rule. *Review of Law and Economics 1*(3), 365–397.

Garoupa, N. and T. S. Ulen (2013). The economics of activity levels in tort liability and regulation. *Research Handbook on Economic Models of Law*, 33.

Garza, A. (2011). Look ma, no hands: Wrinkles and wrecks in the age of autonomous vehicles. *New England Law Review*.

Gershonowitz, A. (1986). Comparative causation as an alternative to, not a part of, comparative fault in strict products liability. *Saint Louis University Law Journal 30*, 483.

Gilles, S. G. (1992). Rule-based negligence and the regulations of activity levels. *Journal of Legal Studies 21*, 319.

Gollier, C., P.-F. Koehl, and J.-C. Rochet (1997). Risk-taking behavior with limited liability and risk aversion. *Journal of Risk and Insurance*, 347–370.

Grady, M. (1987). Why Are People Negligent Technology, Nondurable Precautions, and the Medical Malpractice Explosion. *Northwestern University Law Review 1*.

Grady, M. F. (1988). Why are people negligent technology, nondurable precautions, and the medical malpractice explosion. *Northwestern University Law Review 82*, 293.

Grady, M. F. (2009). Unavoidable Accident. *Review of Law and Economics 5*(1).

Graham, K. (2012). Of frightened horses and autonomous vehicles: Tort law and its assimilation of innovations. *Santa Clara Law Review 52*(4).

Greene, W. (2011). Autonomous cars: Self-driving the new auto industry paradigm. Morgan Stanley Blue Paper.

Greenwood, P. H. and C. A. Ingene (1978). Uncertain externalities, liability rules, and resource allocation. *American Economic Review*, 300–310.

Grimley, W. D. (2000). Comparative fault and solidary delictual obligations: On further consideration. *Los Angeles Law Review 60*, 513.

Grotius, H. (1625). *The Law of War and Peace*. (Francis W. Kelsey, trans., Indianapolis: Bobbes-Merrill Co., Inc., 1925).

Haddock, D. and C. Curran (1985). Economic theory of comparative negligence, an. *Journal of Legal Studies 14*, 49.

Hall, K. L., W. M. Wiecek, and P. Finkelman (1996). *American legal history: cases and materials*. Oxford University Press.

Hay, B. (1997). Allocating the burden of proof. *Indiana Law Journal 72*, 651–679.

Hay, B. L. and K. E. Spier (1997). Burdens of proof in civil litigation: An economic perspective. *Journal of Legal Studies 26*, 413–431.

Hein, G., G. Silani, K. Preuschoff, C. D. Batson, and T. Singer (2010). Neural responses to ingroup and outgroup members' suffering predict individual differences in costly helping. *Neuron 68*(1), 149–160.

Henrich, J., J. Ensminger, R. McElreath, A. Barr, C. Barrett, A. Bolyanatz, J. C. Cardenas, M. Gurven, E. Gwako, N. Henrich, et al. (2010). Markets, religion, community size, and the evolution of fairness and punishment. *Science 327*(5972), 1480–1484.

Hoffman, E., K. McCabe, and V. L. Smith (1996). Social distance and other-regarding behavior in dictator games. *American Economic Review*, 653–660.

Hondius, E. H. (1999). *Modern Trends in Tort Law: Dutch and Japanese Law Compared*. Kluwer Law International.

Hylton, K. N. (1991). Litigation costs and the economic theory of tort law. *University of Miami Law Review 46*, 111.

James, R. W. (1949). Absolute liability for ultrahazardous activities: An appraisal of the restatement doctrine. *California Law Review*, 269–283.

Kahneman, D. (2011). *Thinking. Fast and Slow*. Macmillan.

Kaplow, L. and S. Shavell (1996). Accuracy in the assessment of damages. *Journal of Law and Economics 39*, 191–210.

Kaplow, L. and S. Shavell (2002). Economic analysis of law. In A. J. Hawerback and M. S. Feldstein (Eds.), *Handbook of Public Economics*. Amsterdam, Elsevier Science.

Kornhauser, L. and A. Schotter (1990). Experimental study of single-actor accidents, an. *Journal Legal Studies 19*, 203.

Kornhauser, L. and A. Schotter (1992). An experimental study of two-actor accidents. *New York University CV Starr Center for Applied Economics Working Paper*, 92–57.

Kornhauser, L. A. and R. L. Revesz (1989). Sharing damages among multiple tortfeasors. *Yale Law Journal 98*, 831.

Kornhauser, L. A. and R. L. Revesz (1990). Apportioning damages among potentially insolvent actors. *Journal of Legal Studies*, 617–651.

Kornhauser, L. A. and R. L. Revesz (1994). Multidefendant settlements: The impact of joint and several liability. *Journal of Legal Studies*, 41–76.

Kötz, H. and H.-B. Schaefer (1993). Economic incentives to accident prevention: an empirical study of the German sugar industry. *International Review of Law and Economics 13*(1), 19–33.

Landes, W. M. and R. A. Posner (1980). Joint and multiple tortfeasors: An economic analysis. *Journal of Legal Studies 9*, 517–555.

Landes, W. M. and R. A. Posner (1983). Causation in tort law: An economic approach. *Journal of Legal Studies*, 109–134.

Landes, W. M. and R. A. Posner (1987). *The economic structure of tort law*. Harvard University Press.

Lanzetta, J. T. and B. G. Englis (1989). Expectations of cooperation and competition and their effects on observers' vicarious emotional responses. *Journal of Personality and Social Psychology 56*(4), 543.

Latin, H. (1986). Activity levels, due care, and selective realism in economic analysis of tort law. *Rutgers Law Review 39*, 487.

Lawrence, D. B. (1987). Strict liability, computer software and medicine: Public policy at the crossroads. *Tort and Insurance Law Journal 23*, 1.

LeighAnne, J. and S. Crevier (1992). Comparing two liability rules: Negligence with contributory negligence and comparative negligence. *Term Paper No. 165W92, University of California*.

Leveson, N. G. and C. S. Turner (1993). An investigation of the Therac-25 accidents. *Computer 26*(7), 18–41.

Levine, M., A. Prosser, D. Evans, and S. Reicher (2005). Identity and emergency intervention: How social group membership and inclusiveness of group boundaries shape helping behavior. *Personality and Social Psychology Bulletin 31*(4), 443–453.

Levy, L. B. and S. Y. Bell (1989). Software product liability: Understanding and minimizing the risks. *High Technology Law Journal 5*, 1.

List, J. A. (2007). On the interpretation of giving in dictator games. *Journal of Political Economy 115*(3), 482–493.

Marchant, G. E. and R. A. Lindor (2012). Coming collision between autonomous vehicles and the liability system, the. *Santa Clara Law Review 52*, 1321.

Masserman, J. H., S. Wechkin, and W. Terris (1964). "Altruistic" behavior in rhesus monkeys. *American Journal of Psychiatry*.

Mele, D. (2013). The quasi-autonomous car as an assistive device for blind drivers: Overcoming liability and regulatory barriers. *Syracuse Science and Technology Law Reporter*, 26–64.

Miceli, T. J. (1997). *Economics of the law: Torts, contracts, property, litigation*. Oxford University Press.

Miceli, T. J. (2006). On negligence rules and self-selection. *Review of Law and Economics 2*(3), 349–361.

Miceli, T. J. and K. Segerson (1995). Defining efficient care: The role of income distribution. *Journal of Legal Studies*, 189–208.

Müeller-Langer, F. and H.-B. Schäfer (2009). Strict liability versus negligence. In M. G. Faure (Ed.), *Tort Law and Economics*, pp. 3–45. Edward Elgar.

Nell, M. and A. Richter (1996). Optimal liability: The effects of risk aversion, loaded insurance premiums, and the number of victims. *Geneva Papers on Risk and Insurance. Issues and Practice*, 240–257.

Nell, M. and A. Richter (2003). The design of liability rules for highly risky activities — Is strict liability superior when risk allocation matters? *International Review of Law and Economics 23*(1), 31–47.

Nussim, J. and A. Tabbach (2009). A revised model of unilateral accidents. *International Review of Law and Economics* (06).

Palmer, V. (1988). General theory of the inner structure of strict liability: Common law, civil law, and comparative law. *Tulane Law Review 62*, 1303.

Parchomovsky, G. and A. Stein (2008). Torts and innovation. *Michigan Law Review 107*(2), 285–316.

Parisi, F. (1992). *Liability for Negligence and Judicial Discretion*. Berkeley: California Press.

Parisi, F. (2001). The genesis of liability in ancient law. *American Law and Economics Review 3*(1), 82–124.

Parisi, F. (2013). *The Language of Law and Economics: A Dictionary*. Cambridge University Press.

Parisi, F. and V. Fon (2004). Comparative causation. *American Law and Economics Review 6*(2), 345–368.

Parisi, F. and V. Fon (2005). Causation and responsibility: The compensation principle from Grotius to Calabresi. *Maryland Law Journal 64 (1)*, 108–135.

Parisi, F. and R. Singh (2010). Efficiency of comparative causation. *Journal of Legal Studies 6(2)*, 219–245.

Polinsky, A. M. (1980). Strict liability vs. negligence in a market setting. *American Economic Review*, 363–367.

Polinsky, A. M. and Y.-K. Che (1991). Decoupling liability: Optimal incentives for care and litigation. *Rand Journal of Economics 22*(4), 562–570.

Polinsky, A. M. and S. Shavell (2008). The economic analysis of law. In S. N. Durlauf and L. E. Blume (Eds.), *The New Palgrave Dictionary of Economics*, pp. 20–34. New York: Palgrave Macmillan.

Posner, R. A. (1972). *Economic analysis of law* (1st ed.). Little, Brown and Company, Boston.

Posner, R. A. (1980). A theory of primitive society, with special reference to law. *Journal of Law and Economics*, 1–53.

Privileggi, F., C. Marchese, and A. Cassone (2001). Agent's liability versus principal's liability when attitudes toward risk differ. *International Review of Law and Economics 21*(2), 181–195.

Rand, D. G., J. D. Greene, and M. A. Nowak (2012). Spontaneous giving and calculated greed. *Nature 489*(7416), 427–430.

Ritov, I. and J. Baron (1990). Reluctance to vaccinate: Omission bias and ambiguity. *Journal of Behavioral Decision Making 3*(4), 263–277.

Rotemberg, J. J. (2006). Altruism, reciprocity and cooperation in the workplace. *Handbook of the economics of giving, altruism and reciprocity 2*, 1371–1407.

Rubinfeld, D. L. (1987). The efficiency of comparative negligence. *Journal of Legal Studies*, 375–394.

Sanchirico, C. W. (2004). Evidence tampering. *Duke Law Journal 53*, 1215–1336.

Sanchirico, C. W. (2008). A primary activity approach to proof burdens. *Journal of Legal Studies 37*, 273–313.

Schmitz, P. W. (2000). On the joint use of liability and safety regulation. *International Review of Law and Economics 20*(3), 371–382.

Schwartz, W. F. (1989). Objective and subjective standards of negligence: defining the reasonable person to induce optimal care and optimal populations of injurers and victims. *Georgetown Law Journal 78*, 241.

Shapiro, C. (1991). Symposium on the economics of liability. *Journal of Economic Perspectives 5*, 3–10.

Shavell, S. (1980). Strict liability versus negligence. *Journal of Legal Studies 9*(1), 1–25.

Shavell, S. (1982). On liability and insurance. *The Bell Journal of Economics 13*(1), 120–132.

Shavell, S. (1984). A model of the optimal use of liability and safety regulation. *Rand Journal of Economics 15*(2), 271–280.

Shavell, S. (1987). *Economic analysis of accident law*. Cambridge, Massachusetts: Harvard University Press.

Shavell, S. (2004). *Foundations of economic analysis of law*. Harvard University Press.

Shavell, S. (2008). On optimal legal change, past behavior, and grandfathering. *Journal of Legal Studies 37*, 37.

Shin, H. S. (1998). Adversarial and inquisitorial procedures in arbitration. *Rand Journal of Economics 29*, 378–405.

Singer, T., B. Seymour, J. O'Doherty, H. Kaube, R. J. Dolan, and C. D. Frith (2004). Empathy for pain involves the affective but not sensory components of pain. *Science 303*(5661), 1157–1162.

Singer, T., B. Seymour, J. P. O'Doherty, K. E. Stephan, R. J. Dolan, and C. D. Frith (2006). Empathic neural responses are modulated by the perceived fairness of others. *Nature 439*(7075), 466–469.

Singer, T., R. Snozzi, G. Bird, P. Petrovic, G. Silani, M. Heinrichs, and R. J. Dolan (2008). Effects of oxytocin and prosocial behavior on brain responses to direct and vicariously experienced pain. *Emotion 8*(6), 781.

Singh, R. (2006). On the existence and efficiency of equilibria under liability rules. *NBER Working Paper Series 12625*.

Smith, A. (1759). The theory of moral sentiments, ed. *A. Millar, A. Kincaid & J. Bell. AM Kelley. (Originally published in 1759)*.

Stearns, P. N. (2012). *American fear: The causes and consequences of high anxiety*. Routledge.

Strassfeld, R. N. (1992). Causal comparisions. *Fordham Law Review 60*, 913.

Strumpf, D. (2011). Liability issues create potholes on the road to driverless cars. Available at: `http://online.wsj.com/news/articles/SB10001424127887323854904578264162749109462` (Last access on August 1, 2015).

Talley, E. L. (2013). Law, Economics, and the Burden(s) of Proof. In J. H. Arlen (Ed.), *Research Handbook on the Economic Analysis of Tort Law*. Edward Elgar.

Trimarchi, P. (1959a). Il caso fortuito quale limite della responsabilità per il danno da cose. contributo and una teoria del rischio di inpresa (fortuitous event as a limit of the liability for damage caused by things. contribution to a theory of entrepreneurial risk). *Rivista trimestrale di diritto e procedura civile*, 808 ff.

Trimarchi, P. (1959b). La responsabilità per il fatto dei dipendenti. Contributo and una teoria del rischio di inpresa (Liability for Damage Caused by Employees. Contribution to a Theory of Entrepreneurial Risk). *Rivista di diritto civile*, 604 ff.

Trimarchi, P. (1961). *Rischio e responsabilità oggettiva (Risk and Strict Liability)*. Milano, Giuffrè.

Trimarchi, P. (1967). *Causalità e danno (Causality and Damage)*. Milano, Giuffrè.

Van Velthoven, B. C. (2009). Empirics of tort. In M. G. Faure (Ed.), *Tort Law and Economics*, pp. 453–498. Edward Elgar.

Vanderbilt, T. (2013). Let the robot drive: The autonomous car of the future is here. Available at: `http://www.wired.com/magazine/2012/01/ff_autonomouscars/all/` (Last access on August 1, 2015).

Viscusi, W. K. (1984). Structuring an effective occupational disease policy: Victim compensation and risk regulation. *Yale Journal on Regulation 2*, 53.

Visscher, L. T. (2010). Tort damages. In M. Faure (Ed.), *Tort law and economics*, pp. 153–200. Encyclopedia of Law and Economics, Edward Elgar Publishing.

Wade, J. W. (1983). On the effect in product liability of knowledge unavailable prior to marketing. *New York University Law Review 58*, 734.

White, G. E. (2003). *Tort law in America: An intellectual history*. Oxford University Press.

Wittman, D., D. Friedman, S. Crevier, and A. Braskin (1997). Learning liability rules. *Journal of Legal Studies 26*(1), 145–162.

Yoshihsa, N. (1999). Environmental liability in Japan. In E. H. Hondius (Ed.), *Modern Trends in Tort Law: Dutch and Japanese Law Compared*. Kluwer Academic Publishers.

Young, R., M. Faure, and P. Fenn (2004). Causality and causation in tort law. *International Review of Law and Economics 24*(4), 507–523.

Yu, L. (2000). Book review: Modern trends in tort law: Dutch and Japanese law compared. *Columbia Journal of European Law 6*, 147–148.

Samenvatting

De analyse van het onrechtmatigedaadsrecht is een van de meest invloedrijke en meest ontwikkelde toepassingen van de economische benadering van het recht. Ondanks het enorme aantal publicaties over de economische analyse van het onrechtmatigedaadsrecht, zijn er nog veel onbeantwoorde vragen die verder onderzoek rechtvaardigen. Het algemene doel van dit onderzoeksproject is het traditionele model van het onrechtmatigedaadsrecht te verfijnen om het realistischer te maken, te actualiseren voor wat betreft recente technologische ontwikkelingen, en in overeenstemming te brengen met experimentele resultaten op het gebied van prosociaal gedrag. Dit boek is onderverdeeld in zes hoofdstukken: Hoofdstuk 1 en 6 bevatten respectievelijk een inleiding en conclusie en de overige hoofdstukken zijn geschreven in de vorm van afzonderlijke maar wel gerelateerde artikelen.

Het eerste onderzoeksonderwerp gaat over de optimale toewijzing van 'residual liability' om betere ('second-best') activiteitenprikkels te verstrekken. Met de term 'residual liability' wordt bedoeld de aansprakelijkheid in gevallen waarin zowel de laedens als de gelaedeerde zich zorgvuldig hebben gedragen (d.w.z. wanneer beide partijen niet-nalatig zijn). De toewijzing van residual liability is een beleidsinstrument waarmee prikkels voor het activiteitenniveau beïnvloed kunnen worden. In de traditionele aansprakelijkheidsregimes worden "alles-of-niets"-benaderingen gehanteerd, waarbij de residual liability volledig wordt toegewezen aan hetzij de laedens, hetzij de gelaedeerde, zonder mogelijkheid de schade over de niet-nalatige partijen te verdelen. De keuze tussen conventionele alles-of-niets-regels en schadeverdelingsregels als alternatieve mogelijkheid voor de toewijzing van de residual liability kan een cruciale rol spelen bij het stimuleren van optimale activiteitenniveaus, maar is nooit onderzocht. Deze kwestie komt aan de orde in hoofdstuk 2, waarin wordt aangetoond dat de toewijzing van residual liability in de optimale situatie afhankelijk is van de relevante kenmerken van de activiteiten van de partijen, zoals mate van risico, waarde en interactie in het veroorzaken van ongevalsschade, en van de relatieve risicohoudingen van de partijen. Uit de resultaten blijkt dat regels voor het verdelen van de schade over foutloze partijen in een grote verscheidenheid aan situaties wenselijker zijn dan de traditionele alles-of-niets-regels, bijvoorbeeld wanneer de activiteiten van de partijen dezelfde waarde en mate van risico hebben en wanneer gematigde activiteitenniveaus minder schadelijk zijn dan een hoog activiteitenniveau bij slechts een van beide partijen.

De toewijzing van residual liability is niet alleen relevant voor de stimulering van het activiteitenniveau, maar ook voor investeringen in nieuwe voorzorgstechnologieën. Hoofdstuk 3 gaat over een specifieke soort veiligere technologieën, namelijk geautomatiseerde technologieën, bijvoorbeeld auto's zonder bestuurder en geautomatiseerde drones. Bij de conventionele economische conceptie van het onrechtmatigedaadsrecht wordt het bestaan van twee menselijke actoren verondersteld, de laedens en de gelaedeerde. Met de recente ontwikkelingen in de automatisering verliest deze aanname echter aan betekenis. De vraag die zich opwerpt bij geautomatiseerde activiteiten, is of en hoe het huidige systeem van schuldaansprakelijkheid zich zou moeten ontwikkelen om deze technologieën te stimuleren. In hoofdstuk 3 wordt aangetoond dat het traditionele idee van de redelijke persoon, dat wordt gebruikt om te beoordelen of een actor al dan niet onzorgvuldig was, enigszins zou moeten veranderen om rekening te houden met de mate van automatisering van de activiteiten en dat de zorgvuldigheidsnorm ook activiteitenniveaus moet omvatten wanneer de geautomatiseerde technologie al op grote schaal wordt toegepast of door regelgeving wordt voorgeschreven.

Geautomatiseerde technologieën kunnen niet alleen het aansprakelijkheidsrecht en regulering beïnvloeden, maar ook het bewijsrecht. Sterker nog, hoe meer dergelijke machines interactief en autonoom worden, hoe moeilijker het voor derden is om te bewijzen dat de fabrikant of de gebruiker van het product niet hebben voldaan aan een bepaalde gedragsnorm. In deze gevallen is het cruciaal om vraagtekens te plaatsen bij de traditionele bewijslastverdeling. In hoofdstuk 4 wordt dit pad verder bewandeld door de traditionele bewijslastverdeling bij een onrechtmatige daad te onderzoeken. De twee belangrijkste bevindingen hiervan zijn: ten eerste is het in geen enkel opzicht fundamenteel noodzakelijk om de bewijslast bij de eisers te leggen, in tegenstelling tot wat het traditionele bewijsrecht meestal voorschrijft; en ten tweede resulteert het hanteren van bewijsvermoedens in sturing van individuele gedragingen, doordat zij drie soorten prikkels creëert: prikkels om te investeren in technologie die bewijs kan leveren, om zorg te nemen in situaties waarin de rechter beoordelingsfouten en om excessieve activiteitenniveaus te verlagen. Uit de resultaten blijkt dat de bewijslast zodanig moet worden toegewezen dat het gedragsprikkels versterkt in situaties van bewijsproblemen en hiervoor is een verschuiving van de bewijslast nodig naar de partijen (a) die het meest effectief kunnen investeren in bewijstechnologie; (b) van wie de voorzorgsmaatregelen meer invloed hebben op de ongevalskosten; en (c) die niet al belast zijn met de residual liability.

Hoofdstuk 5 betreft zorgprikkels en beoogt het *feitelijke* zorggedrag van de partijen in kaart te brengen, in plaats van het *theoretische* gedrag, waarop de overige hoofdstukken zich richtten. Hoofdstuk 5 beoogt prosociaal gedrag te evalueren, alsmede ‘other-regarding preferences’ (dus zorg om anderen) in de context van ongevallenpreventie. Uit de resultaten blijkt dat individuen meer middelen uitgeven om te voorkomen dat zij zelf schade lijden dan om te voorkomen dat zij een ander schade berokkenen. Dit is een nieuw resultaat dat aanvullende gedragswetenschappelijke inzichten biedt voor de traditionele economische analyse van het ongevallenrecht en voor de bestaande literatuur over prosociaal gedrag. Deze observatie contrasteert zelfs met een van de erkende resultaten op het gebied van other-regarding preferences, namelijk dat individuen niet graag verantwoordelijk zijn voor slechte resultaten, vooral niet als die van invloed zijn op het welzijn van anderen. De extra kosten van morele verantwoordelijkheid hebben niet tot gevolg dat mensen in een ongevalssituatie schade van anderen hoger waarderen dan die van henzelf. Dit onderzoek biedt een nieuw kader voor het verder onderzoeken van morele voorkeuren en antisociale gedragingen, met verschillende implicaties voor vele juridische en politieke beslissingen over sociale interacties in risicovolle situaties.

Alle hoofdstukken van dit boek dragen interessante ideeën aan voor verder onderzoek en kunnen worden benut om andere kwesties in de economische analyse van het onrechtmatigedaadsrecht en gerelateerde vakgebieden te onderzoeken in met name twee richtingen: modellen op het gebied van onrechtmatige daad verfijnen om menselijk gedrag beter te voorspellen en in experimentele en empirische onderzoeken testen of deze theoretische voorspellingen accurater zijn.