Title
Total Liability for Excessive Harm

Authors
Cooter, Robert D.
Porat, Ariel

Publication Date
2005-08-26

Total Liability for Excessive Harm

by

Robert Cooter
Law School, University of California at Berkeley
email: rcooter@law.berkeley.ed

and

Ariel Porat
Faculty of Law, Tel Aviv University
email: porata@post.tau.ac.il

August 26, 2005

Abstract

The harm that each individual causes others is unverifiable in some circumstances where the total harm caused by everyone is verifiable. For example, the environmental agency can often measure the total harm caused by pollution much easier than it can measure the harm caused by each individual polluter. In these circumstances, implementing the usual liability rules or externality taxes is impossible. We propose a novel solution: Hold each participant in the activity responsible for all of the excessive harm that everyone causes. By "excessive harm" we mean the difference between the total harm caused by all injurers and the optimal total harm. We call this rule "total liability for excessive harm." We show that total liability for excessive harm creates incentives for efficient precaution and activity level. Consequently, actual harm is not excessive and actual liability is nil. For example, the environmental agency can set a target for clean air and announce that each factory is liable for pollution by all factories that exceeds the target. Since the liability rule causes the factories to hit the target, they pay no damages. Thus the environmental agency gains control over emissions without having to monitor individual polluters, and the polluters do not have to pay damages or conform to bureaucratic regulations.

Total Liability for Excessive Harm

Robert Cooter and Ariel Porat*

Introduction

The social harm caused by each individual is often "unverifiable," by which we mean "not provable to a third party." For example, the environmental agency often cannot prove the extent of each polluter's emissions. In these circumstances, implementing the usual liability rules or externality taxes is difficult or impossible. For example, implementing a rule of strict liability requires verifying the damage that individual injurers actually cause. Implementing an externality tax ("Pigouvian tax") also requires verifying the damage that individual injurers actually cause. The same problem arises for a negligence rule, a fine for excessive emissions, or a system of transferable pollution rights.

In many circumstances where the individual's contribution to social harm is unverifiable, the total harm caused by everyone is verifiable. For example, the environmental agency can usually measure total pollution easier than it can measure the harm caused by each individual polluter. In some circumstances like this, we propose a novel rule to control social costs: Hold each participant in the activity responsible for all of the excessive harm that everyone causes. By "excessive harm" we mean the difference between the total harm caused by all injurers and the optimal total harm. We call this rule "total liability for excessive harm."

---

* Robert Cooter is Herman Selvin Professor of Law, University of California at Berkeley. Ariel Porat is Dean and Professor of Law, Tel Aviv University Faculty of Law, and Visiting Professor at the University of Chicago School of Law (Winter 2005). For research assistance, the authors are grateful to Jennifer Shkabatur and Yael Bregman-Eschet. For helpful comments, the authors are grateful to Ronen Avraham, Oren Bar-Gill, David Dana, David Gilo, Aaron Edlin, Daniel Farber, Assaf Hamdani, Ofer Kot, Saul Levmore, Oren Perez, Eric Posner, Peter Siegelman, Catherine Sharkey, Marshall Shapo, David Schorr, Stephen Sugarman, Cass Sunstein, Avraham Tabach, Eric Talley, Omri Yadlin, participants in the Law Faculty workshops at University of Chicago, Haifa University, Northwestern University and Tel Aviv University, participants in the Berkeley Law and Economics workshop, and participants in the Annual Meeting of the American Law and Economics Association held at New York University (May 2005).

We will show that total liability for excessive harm creates incentives for efficient precaution and activity level. Incentives are efficient because each injurer internalizes the full benefit and cost of reducing the harm that he causes. Consequently, actual harm is not excessive and actual liability is nil. For example, the environmental agency can set a target for clean air and announce that each factory is liable for pollution by all factories that exceeds the target. Since the liability rule causes the factories to hit the target, they pay no damages. Thus the environmental agency gains control over emissions without having to monitor individual polluters, and the polluters do not have to pay damages or conform to bureaucratic regulations.

To illustrate with numbers, assume that 2 factories each emit pollution of 150 into a river, and 3 factories each emit pollution of 100, so total pollution equals 600. The environmental agency measures total pollution in the river, estimates the socially efficient level of pollution, and sets a target of 500. If the environmental agency adopts our proposal, it will announce that each factory will be liable for actual pollution that exceeds 500. For example, if the factories continue polluting as in the past, each of the five factories will be liable for 100. As we will show, the factories will respond by reducing pollution until its total equals 500. (The harm function is additive in all of our examples, but the propositions that we prove only require a concave harm function.)

We will show that the rule of total liability for excessive harm is practical under three conditions: (i) total harm is verifiable, (ii) optimal total harm is calculable, and (iii) the number of injurers is not too large. In these circumstances, we recommend adopting our rule because it usually achieves socially efficient abatement at lower administrative and error costs than other liability rules, taxes, fines, or a system of transferable pollution rights.

The rule that we propose has two aspects: “Excessive harm,” refers to the fact that the injurer is liable for harm that exceeds a legal target, and “total liability,” refers to the fact that each injurer is liable for the harm caused by *all* injurers. Part I briefly describes the origins of these ideas. Part II analyzes “excessive harm.” Part III analyzes “total liability.” Part III also develops the important distinction between activity level and participation rate, that existing literature neglects. Part IV refines the model in several ways, including an analysis of irrational or erroneous decision-making, and incentives of victims. Part V concerns applications and examples, which illustrate that the rule of total liability for excessive harm can sometimes solve the "tragedy of the common." After the conclusion in Part VI, a mathematical appendix proves the propositions formulated in the paper.

I. Origins

Our investigation of the literature found some precedent for the idea of total liability and the idea of liability for excessive harm. Although its mathematical foundations are old,[1] the economic analysis of liability is relatively recent. The economic analysis of torts apparently began in the late 1960s and early 1970s.[2] Once the foundation was in place, many papers extended the economic analysis of liability law, some in ways that come close to the idea of total liability.[3] For example, some previous papers analyze

---

[1] For a mathematician, much of the economic analysis of liability and taxation, including the idea of total liability, is implicitly present in the "marginalist revolution" of the late 19th century. This phrase refers to the reworking of economic theory by absorbing calculus into utilitarian reasoning. The marginalist revolution made economists appreciate the importance of marginal costs, as opposed to average costs or total costs. The derivative of a function does not change when a constant value is added to it. So the inputs that maximize a utility function or minimize a cost function do not change when a constant is added to the function. The fact that the optimum depends on marginal values, not infra-marginal values, is the germ of the idea that total liability creates efficient incentives.

[2] Vickery (1968) is a powerful paper that was not absorbed into the legal literature, whereas Calabresi's book *The Costs of Accidents* (*supra* note), was foundational. *See* W. Vickery, "Automobile Accidents, Tort Law, Externalies, and Insurance: An Economist's Critique" 33 *Law and Contemporary Problems* 465-487 (1968). Calabresi does not discuss the possibility that liability should rest on more than one actor. Clearly, he does not suggest that efficient incentives would be achieved if the injurer and victim each bear 100% of the accident's costs. The developing subject was anticipated and described in Richard Posner's *Economic Analysis of Law* (1972). The most relevant discussion concerns the rule of negligence with a defense of contributory negligence, which occurs in Chapter 4, circa page 70. Posner asks whether efficiency requires the injurer or victim to bear the cost of an accident, but he shows no awareness that imposing the cost on both of them would provide efficient incentives. The most important break-through in mathematical modeling of tort liability was made by Brown, who also does not consider the possibility of total liability: J. Brown, "Toward an Economic Theory of Liability" 2 *J. Legal Studies* 323-349 (1973).

[3]Green extended the mathematics. Shavell's influential paper in 1980 on the distinction between precaution and activity level clarified the nature of the problem of incentives for injurer and victim (Calabresi discussed it earlier in his book: Clabresi, *ibid*., pp***). These ideas were subsequently developed in a variety of papers where more than one actor influences the probability or magnitude of an accident. These papers mostly assumed that injurer's damages would be paid to the victim as compensation. Subsequently a discussion developed as to whether injurer's liability might be "decoupled" from plaintiff's recovery. For all that, See J. R. Green, "On the Optimal Structure of Liability Laws" 7 *The Bell Journal of Economics* 553-574 (1976); Stephen Shavell, "An Analysis of Causation and the Scope of Liability in the Law of Torts" 9 *J. Legal Studies* 463-516 (1980); A. Leong, "Liability Rules When Injurers as Well As Victims Suffer Losses" 9 *International Review of Law and Economics* 105 (1989); J. H. Arlen, "Re-Examining Liability Rules When Injurers as Well as Victims Suffer Losses" 10 *International Review of Law and*

the incentive effects of different liability rules when several injurers cause the same harm. To illustrate, when two cars collide and damage each other, the accident would have been avoided if either driver had stayed home. The drivers have efficient incentives if each of them must pay 100% of the cost of the harm suffered by both cars. [4]

In addition, some previous papers analyze the incentive effects of different liability rules when several injurers harm several victims, but no one can verify which injurer caused which victim's harm. To illustrate, several companies manufacture the same drug that causes harm to several users, but the victims cannot prove who manufactured the drug that they took.[5] The literature on the economic analysis of tort liability contains some discussions that come close to, or explicitly mention, what we call "total liability",[6] although we know of no formal analysis.

Unlike tort liability, the literature on externality taxes contains at least one explicit analysis of the rule of total liability. An innovative paper by Segerson analyzes the consequences of taxing each polluter for total pollution that exceeds the social optimum, while also offering a subsidy to each polluter for total pollution that falls short of the social optimum.[7] In addition to literature on pollution, a largely independent economic

---

Economics 233-239 (1990); A. M. Polinsky and Y. K. Che, "Decoupling Liability: Optimal Incentives for Care and Litigation" 22 *Rand J. Economics* 562-570 (1991).

[4] Instead, prevalent liability law causes each of them to pay 50% on average. In intriguing research on automobile accidents, Edlin attempted to measure the extent of this externality. A motorist who drives more miles increases the risk of an accident. Part of this risk translates into higher insurance premiums for others, which Edlin calls the "insurance externality." Part of the external risk, however, does not translate into higher insurance premiums. For example, automobile deaths impose some losses of a kind that are uninsurable. Edlin considers market and tax mechanisms to make drivers internalize the insurance externality and non-insurance externalities that they impose on others. He shows that the revenue capacity for this kind of Pigouvian tax is very high in states where roads are congested. Edlin, however, does not discuss the rule of total liability for excessive harm. There is no reason why he should, since total liability for excessive harm is impractical when applied to automobile accidents because there are too many injurers.

[5] This is the case of separate tortfeasors who are responsible for separate, non-verifiable harms. See Ariel Porat and Alex Stein, *Tort Liability Under Uncertainty* (Oxford University Press, 2001) pp ***. For a discussion of the consequences of a rule of strict total liability, see Golbe and White, *supra* note.

[6] Posner and Landes (1987) and Shavell (1987) published comprehensive books on tort liability, but we cannot find in them the suggestion that several actors who caused separate non-verifiable harms should be held liable for the total harm (or excessive total harm) caused by all actors. See W. M. Landes, and R. Posner, *The Economic Structure of Tort Law* (Harvard University Press, 1987). Especially see *ibid*., Chapter 7: "Joint and Multiple Torts", at pp. 190-227. *See* also S. Shavell, *Economic Analysis of Accident Law* (Harvard University Press, 1987). Especially see *ibid*., Chapter 2: "Liability and Deterrence: Basic Theory", at pp. 5-46. Unfortunately, there are no comprehensive treatments that are more recent.

[7] K. Segerson, " Uncertainty and Incentives for Nonpoint Pollution Control" 15 *Journal of Environmental Economics and Management* 87-98 (1988). Also *see* T. J. Miceli and K. Segerson, "Joint Liability in Torts: Marginal and Infra-Marginal Efficiency" 11 *International Review of Law and Economics* 235-249 (1991).

literature on the principal-agent problem offers some valuable insights into possibilities resembling total liability.[8] In brief, some concepts in the existing literature resemble the rule of total liability for excessive harm, but existing literature does not systematically analyze it or commend it as a practical solution to the problem of social harm.

II. Liability for Excessive Harm

Analyzing the efficiency of alternative liability rules is a significant achievement of the economic analysis of law.[9] We build on this analysis by repeating the familiar results and extending them to our novel rule. We begin with this example.

Example 1. An industrialist operates a factory whose smoke causes harm h to the neighbors. Without abatement, harm h equals 150. Socially optimal abatement reduces harm by 50, so the socially optimal harm h* equals 100. Abatement by 50 costs 25.
Abatement costs have two components. First, by taking precautions costing 15, the factory reduces the actual harm by 30. Second, by reducing production at a cost of 10 in foregone profits, the factory reduces the actual harm by 20.

Consider the incentives created for the industrialist by a rule of strict liability in Example 1. To implement a rule of strict liability, the authorities must be able to verify the actual harm caused by the factory. When implemented effectively, a rule of strict liability for actual harm causes the industrialist to choose between not abating and paying damages of 150, or abating at a cost of 25 and paying damages of 100. Since the later is

---

Miceli & Segerson proposed a form of total liability for ambient pollution, according to which under-achievement of a group's abatement goal results in a tax and over-achievement results in a subsidy. For under-achievement, Miceli & Segerson's tax has the same consequences as our rule of total liability for excessive harm. For over-achievement, however, Miceli & Segerson's subsidy creates a potentially fatal incentive problem. A group that reduces total pollution below the target receives a subsidy equal to a multiple of the total benefit created by their over-achievement. Consequently, by over-achieving they realize a private gain and cause a social loss. Over-achieving is privately profitable and socially costly. The rule of total liability for excessive harm avoids this problem by not paying subsidies for over-achieving relative to the target.

[8] Like the victim and injurer, efficient incentives for the principal and agent are achieved by double liability at the margin. This is true if the principal and agent can both influence outcomes. Similarly, if there are two agents, double liability at the margin gives them efficient incentives. A classical paper that explores the equivalent of total liability for multiple agents is B. Holmstrom, "Moral Hazard in Teams" 13 *The Bell Journal of Economics* 324-340 (1982). The idea takes a somewhat different form in contracts in our theory of "anti-insurance": Robert Cooter and Ariel Porat, "Anti Insurance" 31 *J. of Legal Studies* 203 (2002).

[9] *See* Guido Calabresi, *The Costs of Accidents* (1970); John Brown, "Toward an Economic Theory of Liability," 2 *J. Legal Studies* 323-349 (1973); Stephen Shavell, "Strict Liability vs. Negligence" 9 *J. Legal Studies* 1 (1980). For a summary of conclusions, see Robert Cooter and Thomas Ulen, *Law and Economics* (4th edition, 2003), chapter 8.

cheaper, the industrialist will abate and total pollution will equal 100.[10] These facts correspond to this familiar generalization:

<u>Proposition 1. Strict liability</u>. Assume that m actors participate in an activity with unverifiable activity levels and unverifiable precautions that cause external harm H. Assume that individual harm h^i is verifiable for all m participants. Strict liability of injurer i for the harm h^i creates socially optimal incentives with respect to i's precautions and activity level.

Like all of our generalizations, Proposition 1 requires a concave total harm function H. In contrast, all of our examples simplify by assuming an additive function -- total harm H equals the sum of individual harms.

Instead of strict liability, now consider the consequences of a negligence rule in Example 1. To implement a negligence rule, the authorities must be able to verify the actual precaution taken by the factory. When implemented effectively, a negligence rule causes the industrialist to choose between not taking precaution and paying damages of 30, or spending 15 on precaution and not paying damages. Since the later is cheaper, the industrialist will take precaution. A negligence rule, however, creates no incentive for the industrialist to restrain activity. Consequently, total pollution will equal 120. These facts correspond to this familiar generalization:

<u>Proposition 2. Negligence</u>. Assume that m actors participate in an activity with verifiable precautions x^i_p that cause external harm H. Assume that individual harm h^i is verifiable for all m participants. Assume that law imposes a legal standard of care at the social optimum, x^{i*}_p. If an injurer i's case falls below the legal standard x^{i*}_p, then i is liable for actual harm that would have been avoided if his care had equaled the legal standard. Otherwise i is not liable. i's precautions will be efficient, and i's activity level will be inefficient.

Now we turn to the rule of liability for excessive harm. In Example 1, "excessive harm" equals the difference between actual harm and optimal harm of 100. Liability for excessive harm causes polluter to choose between causing actual harm of 150 and paying damages of 50, or paying abatement costs of 25 and paying damages of 0. Since the later is cheaper, polluter will abate at the socially optimal level. Efficient abatement encompasses both efficient precaution and efficient activity level. Thus the rule of

[10] This discussion implicitly assumes that transaction costs prevent the industrialist from bargaining with the neighbors and making a contract that creates optimal incentives. We also assume that, unlike the industrialist, the neighbors can do nothing to reduce harm.

liability for excessive harm improves on the negligence rule with respect to incentives for injurer's activity level. This conclusion generalizes as follows:

Proposition 3. Excessive harm. Assume that m actors participate in an activity with unverifiable activity levels and unverifiable precautions that cause verifiable external harm H. Assume the individual harm h^i and the optimal harm h^{i*} are verifiable. Individual liability for excessive harm (h^i-h^{i*}) gives the injurer socially optimal incentives with respect to precaution and activity level.

To understand why Proposition 3 is true, compare the difference in incentives between a rule of strict liability and a rule of liability for excessive harm. A rule of strict liability creates efficient incentives by making the injurer internalize the *total* social benefits and costs of precaution and activity level. Total social benefits and costs include marginal and infra-marginal benefits and costs. In contrast, a rule of liability for excessive harm creates efficient incentives by making the injurer internalize the *marginal* social benefits and costs of precaution and activity level. Consequently, the two rules differ in the allocation of infra-marginal costs.

To illustrate by Example 1, a rule of strict liability causes polluter to abate and pay 100 for actual harm, whereas a rule of liability for excessive harm causes polluter to abate and not pay for actual harm of 100. Under both rules, the injurer saves 25 by abating (same marginal incentives), but the first rule allocates optimal harm of 100 (infra-marginal harm) to the injurer and the second rule allocates it to the victims.

Later we will compare systematically the advantages and disadvantages of each type of liability rule.

III. Total Liability

The analysis in Part II assumes that the actual harm caused by the individual injurer is verifiable. In reality, however, victims often suffer from harm caused by many injurers whose individual contributions are unverifiable. To illustrate, non-point source pollution (NPS) occurs when rainfall, snowmelt, or irrigation runs over land or through the ground, picks up pollutants, and deposits them into rivers, lakes, coastal waters, or ground water. As the name suggests, verifying individual contributions of landowners to

NPS pollution is difficult or impossible. However, the total amount of pollution is often verifiable.[11]

Part III explains how to extend liability rules to situations where individual contributions are unverifiable and total harm is verifiable. To begin, we modify the preceding example.

Example 2. Each of m industrialists operates an identical factory whose smoke harms the neighbors. Each industrialist has to submit the factory's design to officials. By examining the designs, officials can verify the total harm H* that all m factories ideally cause. Officials can also verify the total harm H that all m factories actually cause. However, officials cannot verify the actual harm h caused by any individual factory. Nor can officials verify any factory's actual precaution and activity level.[12]

Without abating, the smoke from each factory will cause social harm h equal to 150 and all m factories will cause total social harm H equal to 150m. Socially optimal abatement reduces harm by 50 from each factory. So the optimal individual harm h* equals 100 and the optimal total harm H* equals100m. Abatement by 50 costs 25 for each factory.[13]

Given the restrictions on verifiability in Example 2, officials must resort to liability based on total harm. It is easy to think of many possible rules of liability for

[11] *See* Nonpoint Source Pollution: The Nation's Largest Water Quality Problem: EPA841-F-96-004A, available at http://www.epa.gov/owow/nps/facts/point1.htm). *See also* Jon Cannon "Choices and Institutions in Watershed Management" 25 *Wm. & Mary Envtl. L. & Pol'y Rev.* 379, 388 (2000); Michael P. Vandenbergh "An Alternative to Ready, Fire, Aim: A New Framework to Link Environmental Targets in Environmental Law" 85 *Ky. L.J.* 803, 819-823 (1996-1997). Potential sources of NPS pollution are agriculture, forestry, grazing, septic systems, recreational boating, urban runoff, construction, etc. Today, NPS remains the largest source of water quality problems and the main reason that approximately 40 percent of the surveyed rivers, lakes, and estuaries are not clean enough to meet basic uses such as fishing or swimming. The Environmental Protection Agency (EPA) does not have formal authority to regulate nonpoint source dischargers under the Clean Water Act, nor can most states regulate nonpoint sources under state statutes, instead relying on voluntary or incentive-based mechanisms. (Section 319 to the Clean Water Act requires that states attempt to control nonpoint source pollution; it falls short of requiring states to adopt a regulatory program).Consequently, federal involvement in nonpoint source control most frequently takes the form of nonpoint source assessment, management, and grant award programs, while the requirement from the states to control NPS does not achieve results: *See* Keith Keplinger "The Economics of Total Maximum Daily Loads" 43 *Nat. Resources J.* 1057, 1081 (2003); Esther Bartfeld "Point-Nonpoint Source Trading: Looking Beyond Potential Cost Savings" 23 *Envtl. L.* 43, 53-55 (1993).

[12] *See e.g.* Bartfeld, *supra* note 11, at 89-91 ("Nonpoint source loading and control choices are burdened with uncertainty. Uncertainty affects both the timing and concentration of nonpoint source pollutant loads and the types of control methods that are used to reduce nonpoint source pollution. … nonpoint source load levels are difficult to monitor, and are dependent on variable factors such as precipitation, erosion, and timing of chemical applications").

[13] As in Example 1, we implicitly assume that the neighbors can do nothing to reduce harm, and transaction costs prevent the industrialist and the neighbors from solving the problem by private bargaining.

total harm. We will compare the incentive effects of the following three rules, which seem most important:

i. strict total liability. Each of the m factories is liable for actual total pollution H.
ii. total liability for excessive harm. Each of the m factories is liable for the amount that actual total pollution exceeds optimal total pollution: H-H*.
iii. proportionate liability: Each of the m factories is liable for an equal proportion of total pollution: H/m.

Under a rule of strict total liability, each factory that abates at a cost of 25 reduces its liability by 50. Consequently, each factory chooses to abate and reduce total pollution from 150m to 100m. If the factories' owners are unable to collude, they will not reduce pollution beyond the efficient level of 100m. Under a rule of strict total liability, however, each factory remains liable for 100m. In these circumstances, any factory that reduces pollution by $1 saves all polluters $m. Under such a rule of strict total liability the m participants would gain *together* m times the value of any harm that they prevent. This fact gives the factories an incentive to collude and reduce pollution below the efficient level. This conclusion generalizes as follows:

Proposition 4. Strict total liability. Assume that m actors participate in an activity with unverifiable activity levels, unverifiable precautions and unverifiable individual harm h^i. Assume that actual total harm H is verifiable. If transaction costs prevent collusion among participants,[14] then liability for total harm H gives each injurer socially optimal incentives with respect to precautions and activity level.[15] If the participants can collude, then liability for total harm H gives the injurers incentives for excessive precaution and deficient activity.

To illustrate, Congress enacted the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) in response to a series of well-publicized hazardous waste problems in the 1970s. The statute, commonly known as "Superfund," authorizes EPA to respond to environmental emergencies involving hazardous substances and contaminants, initiate investigations and clean-ups, and take enforcement actions. In order to achieve the remedial purposes of CERCLA, Congress created an exceptionally broad liability scheme under which people who own property containing hazardous substances can be held liable for enormous clean-up costs, even though they were not

---

[14] We later discuss this assumption.
[15] *See* Devra L. Golbe and Lawrence J. White "Market Share Liability and its Alternatives" *Center for Law and Business Working Paper #CLB-99 014* (September 17, 1999).

involved in any hazardous waste disposal activities.[16] Under CERCLA people often pay for much more than the harms they created by their own acts or omissions. CERCLA, consequently, creates a mechanism whose operation often resembles the rule of strict total liability. [17]

According to Proposition 4, if the parties under CERCLA cannot collaborate, the fact that they must sometimes pay for harms created by others does not distort their incentives with respect to precaution and activity level. Indeed, if each party had paid for the entire harm created by all parties, and they were unable to collaborate, each one would have efficient incentives to abate. With collusion, the liable parties would have abated above the efficient level. If collusion fails, however, some factories may prefer to shut down rather than pay for the harm caused by all factories. We return to this point later when we analyze participation rates.

Having discussed incentives under strict total liability, we next consider incentives under the rule of total liability for excessive harm. When this rule is applied to Example 2, each factory that abates at a cost of 25 reduces its liability by 50. Abating reduces total pollution from 150m to 100m. Consequently, each factory has an incentive to abate at the efficient level. Under a rule of total liability for excessive harm, each factory's liability falls to zero. Consequently, each participant gains nothing if actual total harm H falls below optimal total harm H*.[18] So they have no reason to collude or reduce pollution any further. The following proposition generalizes these conclusions:

Proposition 5. Total liability for excessive harm. Assume that m actors participate in an activity with unverifiable activity levels, unverifiable precautions and unverifiable individual harm h^i. Assume that actual total harm H and optimal total

[16] Jeffrey A. Kodish "Restoring Inactive and Abandoned Mine Sites: A Guide to Managing Environmental Liabilities" 16 J. Envtl. L. & Litig. 381, 384-385 (2001).

[17] CERCLA creates the following four categories of Potential Responsible Parties: 1) Current owners or operators of a facility; 2) owners or operators of a facility at the time of disposal of hazardous substances; 3) persons who generated or arranged for the disposal or treatment of hazardous substances; and 4) transporters of the hazardous substances, if the transporter selected the disposal or treatment site.42 U.S.C. 9607(a)(1)-(4) (1994). Except where the defendant can prove a reasonable basis for apportioning the harm, the courts adopted a broad rule that imposes strict joint and several liability, and retroactive liability for cleanup. In many cases, this scheme is considered to be too harsh on defendants. So it was severely criticized. *See, e.g.*, Lynda J. Oswald "New Directions in Joint and Several Liability under CERCLA?" 28 *U.C. Davis L. Rev.* 299 (1995); John Copeland Nagle "CERCLA, Causation, and Responsibility" 78 *Minn. L. Rev.* 1493 (1994).

[18] Even under a rule of total liability for excessive harm, errors or irrationalities might cause the parties to gain from collusion. We discuss errors and irrationalities later in the paper.

harm H* are verifiable. Liability for excessive harm H-H* gives each injurer efficient incentives with respect to precautions and activity level.

In spite of its advantages, this rule may seem unfair because individual injurers are threatened with liability for harm caused by others. When individual injurers are rational and make no errors, however, the incentives created by the rule cause actors to behave optimally, so actual total harm is not excessive and the threat of liability is not carried out.

Now we turn to proportionate liability. When a rule of proportionate liability is applied to Example 2, each factory that abates at a cost of 25 reduces its liability by 50/m. If m is larger than 2 in Example 2, then abating costs each factory more than it saves in liability costs, so the factories will not abate. Unlike strict total liability and total liability for excessive harm, a rule of proportionate liability creates deficient incentives for precaution and restraint of activity.[19] This conclusion can be formalizes as follows.

<u>Proposition 6. Proportionate liability</u>. Assume that m actors participate in an activity with unverifiable activity levels, unverifiable precautions and unverifiable individual harm h^i. Assume that actual total harm H is verifiable. Also assume that transaction costs prevent collusion among participants. Liability for proportionate harm (H/m) gives each injurer deficient incentives with respect to precautions and activity level.

The economic analysis of liability usually distinguishes between precaution and activity level. For example, a motorist decides how carefully to drive and how much to drive. Similarly, an industrialist decides how carefully to produce and how much to produce. Prior to deciding precaution and activity level, an actor must often decide whether or not to participate. For example, in order to participate in driving a person needs a car. Furthermore, car ownership is usually easier to verify than other factors affecting accidents such as how often or carefully one drives. Similarly, in order to participate in manufacturing a person needs a factory, and the construction of a factory is easier to verify than the care and level of its activities. Because of the difference in verifiability, this paper emphasizes the distinction between activity level and participation rate that previous literature mostly neglects.

[19] Notice however, that when individual precautions and activity level is verifiable, a rule of proportionate liability may be optimal. *See* Ariel Porat and Alex Stein, *Tort Liability under Uncertainty* (Oxford University press, 2001) 101-59. Also notice that, according to the Coase Theorem, perfect collusion would solve the problem of deficient precaution caused by this rule.

The incentives for participation are a decisive objection to the rule of strict total liability. This rule causes each of the m participants in the industry to pay damages of H, whereas the harm that each one causes is only h^i. To illustrate numerically by Example 2, if m equals 5, then strict total liability causes each of the 5 participants in the industry to pay damage of 500, whereas the harm that each one causes is only 100. A rule of strict total liability allocates much more infra-marginal cost to each injurer than he actually causes. Consequently, the rule over-burdens participation in the industry. The result is too little investment and participation.[20]

For the rule of total liability for excessive harm, the analysis of participation reaches a different result. As we have explained, total liability for excessive harm gives each participant in an industry incentives to abate optimally, so total harm H equals H* and liability is zero. Instead of being zero, the harm that each one causes is h^i. To illustrate by example 2, total liability for excessive harm causes each of the m participants in the industry to pay damage of 0, whereas the harm that each one causes is 100. Under these circumstances, injurers cause somewhat more harm than they pay in damages, which results in somewhat too much participation.

The rule of strict total liability grossly over-burdens participation, and the rule of total liability for excessive harm modestly under-burdens participation. In principle, however, a remedy exists in either case. Factory ownership, which requires initial investment, is usually easier to verify than other factors affecting pollution, such as how much a factory produces or abates. Because of the difference in verifiability, participation and activity level should be distinguished from each other. When participation is easy to observe, we advocate a participation tax to deter over-participation.

Optimal incentives for participation require the injurer to internalize the cost that his participation imposes on others. The liability rule causes the participant to internalize some of these costs. Consequently, the participation tax should equal the social costs of participation that optimal liability does *not* impose. Under the rule of strict total liability, each participant has optimal incentives for precaution and activity level, so injurer i imposes social costs h^{*i} on others. Under the rule of strict total liability, each participant

[20] If the rule of strict liability for total harm allows two factories to cut their total liability in half by merging, the rule will induce inefficient mergers by their desire to reduce liability.

faces liability H*. Thus the social costs of participation that optimal liability does not impose, which is the optimal participation tax, equals h^{*i}–H*. This is typically a large negative number, so each participant receives a large participation subsidy. To illustrate by Example 2, the optimal participation subsidy under a rule of strict total liability equals 100(m-1). Given 5 participants, the optimal participation subsidy equals 400.

Similarly, under the rule of total liability for excessive harm, each participating injurer i imposes social costs h^{*i} on others. Under the rule of total liability for excessive harm, each participating injurer faces liability 0. Thus the social costs of participation that optimal liability does not impose, which is the optimal participation tax, equals h^{*i}. To illustrate by Example 2, the optimal participation tax under a rule of total liability for excessive harm equals 100.

The following generalization formalizes this result.

Proposition 7: Optimal participation. Assume that n actors potentially participate in an activity. Assume that participants face liability l^{*i} that induces socially optimal precaution and activity level. Assume that external harm H increases with more participation. Incentives for an optimal number of the n actors to participate are achieved if each actor i who participates pays a lump sum tax equal to the harm h^{*i} caused by participating at optimal level of activity and precaution, minus the liability l^{*I}.

The numbers in the preceding example suggest that the optimal participation subsidy under a rule of strict total liability is much larger than the optimal participation tax under a rule of total liability for excessive harm. For this reason, the later is more practical and easier to implement than the former.

Now we summarize our conclusions about participation. A rule of strict liability for individual harm causes each injurer to internalize the harm caused by his participation, as required for efficient participation. A participation tax is unnecessary. In contrast, a rule of strict total liability causes each injurer to internalize H*-h^{*i} *more* harm than he actually causes. Consequently, inducing optimal participation under a rule of strict total liability requires a participation subsidy equal to H*-h^{*i}, which can be a very large number.[21] Without the participation subsidy, a rule of strict total liability causes

[21] Notice that the subsidy depends on optimal values H*-h^{*i}, not on actual values H-h^i. If actual values determine the subsidy, injurers will recognize that the subsidy will increase as the total harm H increases, which distorts their incentives. If ideal values determine the subsidy, then actual precautions and actual

deficient participation. In contrast, a rule of total liability for excessive harm provides incentives for injurers to meet the target H* for optimal harm, in which case their liability equals zero. When liability is zero, Proposition 7 indicates that optimal incentives for participation requires each injurer to pay lump sum tax equal to the harm h^{*i} caused by participating at optimal precaution and activity level.[22]

We have shown that optimal participation can be achieved by a rule of total liability for excessive harm, combined with a participation tax equal to the harm that the injurer causes when his behavior is optimal. To illustrate by Example 2, assume that the environmental agency imposes a rule of total liability for excessive harm. In addition, the environmental agency examines the designs for factory i and determines that its pollution will cause harm of 100 when it abates optimally. To give the industrialist efficient incentives to build or not build the factory, the environmental agency should assess a participation tax of 100 for building the factory.

We summarize the main conclusions of our paper in two tables. Table 1 shows the variables that must be verifiable in order to implement each of the liability rules. Table 2 assumes that participation subsidy or tax is unavailable and compares the efficiency of the most important liability rules.

Table 1: Verification Requirements

Liability rule	**Total Harm H**	**Ideal Harm H***	**actual individual harm h**	**ideal individual harm h***	**actual individual precaution x**	**ideal individual precaution x***
total strict liabililty	√					
total excessive harm	√	√				
individual strict liability			√			
individual excessive harm			√	√		
negligence			√		√	√

activity level does not affect the subsidy, so the existence of the subsidy does not change injurer's incentives for precautions and activity level.

[22] Notice that the tax depends on optimal values h^{*i}, not on actual values h^i. See *supra* note.

Table 2: Efficiency of Injurer's Behavior

Liability Rule	Precaution?	Activity Level?	Participation? (assumes no participation tax or subsidy)
total strict liability	**collusion problem**	**collusion problem**	far too low
total excessive harm	√	√	moderately too high
individual strict liability	√	√	√
individual excessive harm	√	√	moderately too high
Negligence	√	too high	moderately too high

IV. Refining the Model

Part IV refines the model in several ways, including the following topics: errors by authorities, search for the social optimum, irrational decision-making by actors, victims' incentives, bankruptcy, synergy, and strategic behavior.

Errors

As explained, the rule of total liability for excessive harm creates incentives for efficient precaution and activity level. This result, however, requires the authorities to make no errors in setting the target H* and observing total harm H.[23] This section explains what happens when the authorities make errors in assessing liability.

One type of error consists in the authorities overestimating or underestimating the actual harm H. We call $H+\varepsilon$ the harm *observed* by the authorities, when $\varepsilon>0$ implies an overestimation and $\varepsilon<0$ implies an underestimation. Under the rule of total liability for excessive harm, each injurer is liable when the total *observed* harm exceeds the social

[23] The TMDL (total maximum daily load) rules, established under the Clean Water Act, § 303 by each state, are an example for setting the target H*. A TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources. *See* http://www.epa.gov/owow/tmdl/intro.html; James Boyd "The New Face of the Clean Water Act: A Critical Review of the EPA's New TMDL Rules" 11 *Duke Env. L. & Pol'y F.* 39 (2000) (providing an overview of TMDL's program and considering the economic implications of movement toward a TMDL-driven regulatory system); Keplinger, *supra* note (offering an econmic analysis of the TMDL rules); Paula J. Lebowitz "Land Use, Land Abuse and Land Re-Use: A Framework for the Implementation of TMDLs for Nonpoint Source Polluted Waterbodies" 19 Pace Envtl. L. Rev. 97 (2001) (providing guidance for developing implementation plans for TMDLs).

optimum, $H+\varepsilon > H^*$, in which case liability equals the total observed excess $H+\varepsilon - H^*$. Otherwise the injurer is not liable.

Another type of error occurs when the authorities observe the social optimum H* with error ε, which we write $H^*+\varepsilon$. The authorities over-estimate the socially optimal harm when $\varepsilon>0$, and the authorities under-estimate the socially optimal harm when $\varepsilon<0$. Under the rule of total liability for excessive harm, each injurer is liable when the total harm exceeds the observed social optimum, $H> H^*+\varepsilon$, in which case liability equals the total observed excess $H- H^*-\varepsilon$. Otherwise the injurer is not liable.

With a rule of total liability for excessive harm, the situation where the authorities make an error in observing the target H* is mathematically identical to the situation where authorities make an error in observing the actual harm H. To be more precise, over-estimating actual harm H and attributing more harm to injurers than they actually cause is mathematically equivalent to under-estimating the socially optimal harm H* and setting the target too low. In either case, the error causes injurers whose behavior was socially optimal to be held liable by mistake.

When the kind of error that we are discussing occurs, it is often a random error. Random errors can be unbiased, in which case their expected value is zero: ($E(\varepsilon)=0$). In the presence of random, unbiased errors in observing total harm H or setting ideal harm H*, the rule of total liability for excessive harm induces socially optimal precaution and activity levels among risk-neutral injurers. This is a specific form of the proposition that random, unbiased errors do not change the behavior of risk-neutral actors.

Alternatively, random errors can be biased, in which case their expected value is not zero: (($E(\varepsilon)\neq 0$). For errors biased towards lower liability (errors of under-estimation of actual harm H or over-estimation of socially optimal harm H*), we can show that the rule of total liability for excessive harm induces too little precaution and too much activity. Errors biased towards lower liability result in too much harm because injurers escape liability at a level of actual harm that is excessive. Having escaped liability, injurers have no incentive to reduce social harm any further. This conclusion is robust.

Conversely, for errors biased towards higher liability (errors of over-estimation of actual harm H or under-estimation of socially optimal harm H*), the rule of total liability for excessive harm induces socially optimal precaution and activity level. To see why, consider the situation of an injurer whose behavior is socially optimal. By assumption the authorities mistakenly set the target too low, or they mistakenly observe more total harm than actually occurs. Consequently, even though all of the injurers behave optimally, they still face liability. A small increase in precaution or a small decrease in activity level by any injurer will reduce his liability. The injurer thus internalizes the benefits and costs of reducing the total harm. Since his behavior is already socially optimal, a small increase in precaution or decrease in activity costs him more than the resulting reduction in liability. The injurer, consequently, prefers to continue behaving optimally with respect to precaution and activity level. (We discuss participation rate later.) Thus the error biased towards higher liability does not cause injurers who behave optimally to stop doing so.

With respect to errors biased towards higher liability, however, the incentives for optimal behavior are not robust. In these circumstances, injurers have a strong incentive to collude with each other in order to reduce the level of actual harm H below the socially optimal level H*. By colluding to reduce actual harm H, the injurers can eliminate the excessive harm mistakenly observed by the authorities. Since each injurer is liable for the total excessive harm mistakenly observed by the authorities, the group of injurers saves a lot by escaping liability. In sum, an error by the authorities that increases liability under a rule of total liability for excessive harm provides socially optimal incentives to injurers who act strictly individually, but strong incentives also exist to collude and over-perform relative to the social optimum.[24]

To illustrate, assume that each of 5 polluters cause harm of 100, optimal harm H* is 500, and the authorities mistakenly set the target at 400. Under the rule of total liability for excessive harm observed by the authorities, if the polluters continue at the socially optimal level of pollution, each one pays 100 in mistaken liability and the total liability paid by all of them equals 500. By colluding and reducing pollution from 500 to 400, the 5 polluters reduce their total liability from 500 to 0.

Proposition 8 formulates these conclusions, which the appendix proves.

> <u>Proposition 8. Total liability for excessive harm with random additive error</u>. Assume that m risk-neutral actors participate in an activity with unverifiable activity levels and unverifiable precautions. Assume that actual total harm H and

[24] Another reason the result is not robust, which we do not discuss, is that a discontinuity in social costs creates an incentive to over-perform in order to escape liability. The problem of discontinuity is discussed extensively in the literature on negligence. For a summary, *see* Cooter and Ulen, *supra* note 1, Chapter 8.

optimal total harm H* are verifiable with additive error ε. When H+ε>H*, each injurer is totally liable for H-H*+ε. Otherwise each injurer is not liable.

(i). If the expected error is unbiased (E(ε)=0), then the injurer has socially efficient incentives with respect to precautions and activity level.

(ii). If the expected error is biased towards a legal standard that is too low (E(ε)<0), then the injurer has incentives for too little precaution and too much activity.

(iii). If the expected error is biased towards a legal standard that is too high (E(ε)>0), then the injurer has incentives to take optimal precaution and activity (but optimal incentives are vulnerable to collusion).

Instead of charging people who increase social harm, why not subsidize people who reduce it? The incentive effects of liability for falling short of a target often resemble the incentive effects of subsidies for reaching a target. In the usual case, practical reasons favor liability over subsidies. This conclusion is especially true when discussing the rule of total liability for excessive harm. A rule that subsidized injurers for reducing total actual harm (H) below the socially optimal harm (H*) provides strong incentives for injurers to collude and reduce harm below the social optimum. Therefore we do not advocate the adoption of such rule.

We have discussed the consequences of random error on precaution and activity level. We also note briefly the consequences of random error on participation. Unbiased error does not change the expected payoffs for risk neutral injurers, so unbiased error does not change their incentives for participation. Error biased towards a legal standard that is too low increases the payoffs from participation. Consequently, participation will increase (assuming the participation tax remains constant). Conversely, error biased towards a legal standard that is too high decreases the payoffs from participation. Consequently, participation will decrease (assuming the participation tax remains constant).

We have explained that error biased towards a legal standard that is too low causes participation to increase, and error biased towards a legal standard that is too high causes participation to decrease. The social value of this increase or decrease in participation depends on the participation tax. When the participation tax is optimal, an error in assessing liability that causes participation to increase creates a problem of over-participation, whereas an error that causes participation to decrease creates a problem of under-participation. In reality, the participation tax is likely to be nil. When the participation tax is nil, an error in assessing liability that causes participation to increase aggravates the problem of over-participation, whereas an error that causes participation to decrease ameliorates this problem.

Search

Proposition 8 concerns the consequences of errors by authorities on the incentives of others. Another line of inquiry concerns the ability of authorities to learn and correct their errors. To illustrate, consider the situation where the authorities have difficulty estimating the optimal social harm H*. In these circumstances, the authorities might search for the optimum and converge towards it by iteration. The authorities might begin by allowing deliberately more harm than the social optimum. Thus the authorities set a target H_t well above H* in the first year. As long as H_t is higher than the social optimum, all the firms would meet the target and pay no damages. In the next year, the authorities might decrease H_t. The authorities can repeat this process over several years. As H_t decreases, eventually a point will be reached where further increases in abatement costs a firm more than liability, so the firms will fall short of the target and begin to pay damages. At that point, the authorities would know that H_t is marginally lower than H*, so they should increase H_t slightly and stop making changes. In brief, the authorities can proceed iteratively until the firms reveal that their marginal cost of abatement is at least as high as the marginal social cost of the harm from pollution. This is essentially the same process in theoretical models of search for the Hand Rule standard of negligence or the optimal Pigouvian tax.[25]

After searching and finding the social optimum H*, the authorities should be alert to the possible emergence of new technologies that lower abatement costs and cause the optimal harm H* to decrease. In response to such technical improvement, the authorities must decrease the target in order to keep it equal to the social optimum H*. If they don't do it, actors will have deficient incentives to use new technologies.

[25] Add cite***.

Irrationality

We have analyzed the consequences of simple, additive errors by authorities in observing actual or optimal harm.[26] Now we turn to the consequences of errors or irrationality by some actors when deciding to abate. We will explain how rational actors respond to the presence of irrationality by some other actors. We will not discuss how to influence irrational actors, which would require a psychological theory of behavior that we have not developed in this paper.

We can model irrationality as an error that causes actual behavior to deviate from rational behavior. We have explained that rational actors respond to a rule of total liability for excessive harm by causing total harm H to equal the target H*. We can analyze irrationality as a situation where actors respond to a rule of total liability for excessive harm by causing total harm H *not* to equal the target H*. From the viewpoint of rational actors, irrational behavior by others can be modeled as a random error ε such that $H=H^*+\varepsilon$. Proposition 8 already describes the effects of such a random error on the behavior of rational actors. Thus we can reinterpret Proposition 8 as an account of the incentive effects that irrational actors impose on rational actors.

For example, assume that irrational over-performance by some actors tends to offset irrational under-performance by others, so the expected error from irrational actors is nil: $E(\varepsilon)=0$. In these circumstances, Proposition 8 asserts that *rational* actors will choose the socially efficient precaution and activity level. (The irrational actors are wasting resources by taking too much or too little precaution, but we offer no theory for how to influence their behavior and improve it.)

In contrast, if irrational over-performance by some actors exceeds irrational under-performance by other actors, so that ($E(\varepsilon)<0$), then Proposition 8 asserts that rational actors will abate too little. Finally, if irrational under-performance by some actors

[26] Proposition 8 and the discussion leading up to it assumes the error in observation by authorities adds to, or subtracts from, the actual harm H or the optimal harm H*. Our conclusions would be quite different if the error multiplied the actual harm H or optimal harm H*. To illustrate multiplicative error, the authorities may underestimate actual harm by 10%, or the authorities may overestimate the socially optimal harm by 15%. With a multiplicative error, the extent of liability under the rule off total liability for excessive harm can be written $H(1+\varepsilon)-H^*$, or $H-H^*(1-\varepsilon)$. Multiplicative error affects marginal values, whereas additive error often does not affect marginal values. The effect of multiplicative errors on marginal values change incentives of injurers in situations where additive errors cause no change.

exceeds irrational over-performance by other actors, so that ($E(\varepsilon)>0$), then Proposition 8 asserts that rational actors who do not collude will abate efficiently, but rational actors have an incentive to collude.

We have been discussing irrationality that takes the form of calculation errors by some actors. Under a rule of total liability for excessive harm, irrational actors who take too little precaution and too much activity reduce their own payoffs. That is why their behavior is irrational. However, they also reduce the payoffs of all the other injurers. Consequently, the other injurers have a strong incentive to help irrational actors to correct their errors, start behaving rationally, and abate more.

Conversely, when an irrational actor takes too much precaution and too little activity, the rational actors benefit from this mistake and they have no incentive to help the irrational actors correct their errors, start behaving rationally, and abate less.[27]

Victims Incentives

We have been assuming that injurers can reduce social harm H and victims cannot reduce it. Now we relax the assumption that victims cannot influence the extent of social harm and we discuss briefly the incentives that alternative liability rules give victims. In general, when victims do not receive compensation, they internalize the benefits as well as the costs of their actions, so victims' incentives are socially efficient.[28] Consequently, if injurers are liable to the state and not liable to the victims, as with a pollution tax, then victim's incentives are efficient.

In terms of our notation, assume that injurers can reduce harm H by restraining their activity levels $\underline{y}$ and taking precaution $\underline{x}$, and victims who suffer harm H can reduce it by acts z, so $H=H(y,x,z)$. The acts z may encompass precaution and activity level. If injurers are liable to the state and not to victims, then victims have incentives to set z equal to the social optimum z^*.[29]

---

[27] We implicitly assume that the authorities do not respond to irrational actors by adjusting the target. If the legal target adjusts to irrational actors, the analysis becomes more complicated.

[28] Similarly, a rule of negligence in simple economic models induces non-negligent behavior by injurers, so victims face the same incentives as under a rule of no liability. This proposition is proved in many places, including Cooter and Ulen, *supra* note 1, Chapter 8.

[29] If liability equals $H-H(y^*,x^*,z)$, and if $z=z^*$ when $y=y^*$ and $x=x^*$, then $(y,x,z)=(y^*,x^*,z^*)$ is an equilibrium.

Instead of being liable to the state, injurers may be liable to the victims. If victims can increase their compensation by decreasing z, then they will have an incentive to set z below the social optimum z*. For example, victims will chose z lower than z* if their compensation equals the difference between actual harm H(y,x,z) and optimal harm H(y*,x*,z*).

To avoid this problem, the state should calculate compensation by replacing the actual harm H(y,x,z) with the hypothetical harm that would result given the actual behavior of injurers and ideal behavior of victims H(y,x,z*). When liability follows this formula, victims receive compensation H(y,x,z*) - H(y*,x*,z*), which they cannot influence by their actual behavior z. Implementing this formula, unfortunately, may be difficult or impractical because of the difficulty in verifying H(y,x,z*).

Risk of Bankruptcy

The possibility of bankruptcy blunts the injurer's incentive effect of liability. Because of bankruptcy, the threat of liability is effective only to the extent of the injurer's assets. To illustrate, assume that a potential injurer must choose between an act that risks social harm of 50 and an act that risks social harm of 100. In order for the threat of liability for actual harm to provide an incentive to choose the first act instead of the second act, the injurer's assets must exceed 50. If the injurer's assets equal 50, then the injurer will internalize the threat of liability up to 50, and externalize through bankruptcy the threat of liability exceeding 50.

Externalizing risk through bankruptcy is a problem for any liability rule. The problem exists for the rule of total liability for excessive harm and for all of the alternative rules. There is, however, one way that bankruptcy affects the rule of total liability for excessive harm differently from a rule of individual liability. Under the rule of total liability for excessive harm, each actor pays for the total excessive harm, regardless of the ability of other actors to pay. Consequently, insolvency by one actor does not directly affect other actors' liability. The only effect is indirect. If one actor knows he is under a substantial risk of insolvency, he may refrain from abating, since he would be unable to pay the excessive harm anyway. By refraining from abating, he will increase the total liability that other actors will have to pay. This indirect effect of one injurer's bankruptcy on other injurers is absent for rule of individual liability when each injurer is liable for a separate harm that he creates.

Note however, that a similar effect to the one described above exists under a rule of joint and several liability. When several injurers create one inseparable harm for which they are all jointly and severally liable, the injurers have contribution claims against each other. In these circumstances, the insolvent injurer's proportion of liability will be born by the solvent injurers. In this respect, joint and several liability is like a rule of total liability for excessive harm.

The indirect effect of one injurer's bankruptcy on others raises a general question for the rule of total liability for excessive harm: When one or more injurers inevitably fails to abate optimally, so total harm inevitably exceeds the target set by the authority, should the authority adjust the liability of the others? Such a failure could result from insolvency, irrationality, or criminality. The optimal total harm (H*) could be adjusted to take into account the unexpected circumstances. Thus the authority will treat inevitable failure to abate by one of the injurers in the same way that it treats natural harm that is outside of human control. In particular, if harm increases from unexpected circumstances, the target H* will be set higher than if the unexpected circumstances had not occurred.

Synergy

In our numerical examples, each participant creates separate harm that sum to the total harm for society. In reality, the harm created by one participant is not easily separated from the harm created by others, In these circumstances, the law says that several actors are "but-for causes" of one harm. Although total harm to society may not be the sum of individual harms, the marginal harm caused by each actor may be calculable. The marginal harm equals the change in total harm caused by a small change in an individual's activity level or precaution. Our propositions assume that each actor can calculate his marginal contribution to the total harm. Our propositions also assume that, as inputs increase, marginal benefits decrease and marginal costs increase.

The technical name for this condition is a "concave social welfare function."[30] By assuming that functions are concave, we assume the existence of a unique social optimum. A concave function is analogous to a mountain with a single peak. Individual actors are analogous to a climber in a fog. Although the climber can only see for a few meters, he can eventually reach the peak by following the rule, "Always to up."

We have explained that the truth of our propositions depend on the concavity of the underlying functions, not on the absence of synergies. To illustrate, assume that if A produces output of 1 and no one else produces, then external harm equals -1. Similarly, if B produces output of 1 and no one else produces, then total harm equals -1. If A produces output of 1 and B produces output of 1, then total harm equals 5.3. This fact illustrates synergy in harm. These numbers, however, could be particular values of a continuous, concave function.[31] If so, a rule of total liability for excessive harm will cause A and B to expand production until they reach the social optimum and then stop.

In contrast, a non-concave function create problems for decentralized decision making because more than one local optimum exists, and decision makers may find a local optimum and never find the global optimum. If the marginal values decrease at first and then start to increase, the function is not concave. Consequently, individuals who base their decision on marginal values may not find the optimum. A non-concave function is analogous to a mountain with several peaks, one of which is the "true peak" and the others are "false peaks." A climber who follows the rule, "Always to up," may ascend a false peak and never find the true peak, just like decentralized decision makers may not find the optimum in a non-concave economy.

Strategy

Our propositions show that, under the rule of total liability for excessive harm, the social optimum is an individual optimum for non-strategic actors. By "non-strategic" we

---

[30] A function $f(x_1,x_2)$ is concave (weakly) if and only if, for all (x_1,x_2) the following conditions hold:

$$f_{11}(x_1,x_2) \leq 0$$
$$f_{22}(x_1,x_2) \leq 0$$
$$f_{11}(x_1,x_2) \cdot f_{22}(x_1,x_2) \leq f_{12}(x_1,x_2)^2.$$

[31] For example, the harm function might have the form $-H=-A-B-A^2B^2$, and the social welfare function might have the form $2(A+B)-H$.

mean that each actors does what is best for himself under the assumption that other actors will not change what they are doing. Under this assumption, actors take the behavior of others as given, just like firms in a model of perfect competition.

This paper concerns situations where the authorities can verify total harm and cannot verify individual behavior. With this distribution of information, the rule of total liability for excessive harm solves the problem of socially optimal incentives for non-strategic actors. If the authorities cannot verify individual behavior, then each participant is unlikely to be able to observe the individual behavior of other participants. In other words, the circumstances where the authorities cannot verify individual harm are usually circumstances where the individuals cannot observe each others' behavior. When individuals cannot observe each others' behavior, they naturally assume that other actors will not respond to what they do. When information is distributed as in our model, the most natural assumption is that individuals behave non-strategically.

Although non-strategic behavior is most likely, we will consider some possibilities for strategic behavior. The polar opposite of non-strategic behavior is perfect collusion. Perfect collusion implies that all actors cooperate with each other to maximize their joint payoffs. In our model, the aim of collusion is to minimize the total cost of liability and abatement for the parties. Under the rule of total liability for excessive harm, the parties minimizes their total cost of liability and abatement by meeting the target H* and avoiding liability. Thus, when the parties collude perfectly, the rule of total liability for excess harm induces socially optimal results. Indeed, collusion has the advantage of enabling actors to help correct each others' mistakes. This fact suggests that the rule of total liability for excessive harm will prove robust and practical.

There is a danger, however, that benign collusion over liability and abatement might prompt other harmful forms of collusion. For example, collusion over abatement might lead to collusion over prices. The tools or antitrust law are available to deal with this problem. Another fear is that collusion over abatement will lead to political lobbying to lower the target level of harm H* and keep it below the social optimum. The problem of setting standards and escaping political distortions is not special to our rule of liability. It applies to all liability rules and regulations. An important topic for future research is to explore politically realistic means to set the target H* at the social optimum.

Collusion involves cooperation. Another topic to explore is forms of strategic behavior that do not involve cooperation. Far too many possibilities exist to discuss them all. To convey a sense of the problem, we will discuss two of them: the game of chicken and the practice of predatory pricing, which can result in a socially inefficient equilibrium.

A sinister possibility is that an actor threatens to take too little precaution and too much activity in order to intimidate others. In other words, an actor threatens that he will impose liability on himself and everyone else unless they take steps to eliminate liability for everyone. This is a form of the game of "chicken". To play chicken under the rule of total liability for excessive harm, an injurer refuses to abate efficiently in order to force other injurers to abate excessively.

To illustrate by Example 2, assume that there are 5 identical actors, the optimal total harm H* is 500, the total actual harm H is 550, and the law imposes total liability for excessive harm. After 4 actors reduce their individual excessive harm to zero, the 5th actor considers whether to abate and reduce his excessive harm to zero as well. He may reason that if he does not abate, the other four actors will have very strong incentives to collude and increase abatement. By colluding and eliminating excessive harm of 1, the other four actors can save themselves 4.

We explained that the most natural assumption in our model is that the 5 actors cannot observe each others' abatement efforts. If no one knows how much each of the others abate, then they cannot play chicken. Even if they can somehow overcome the information obstacle and play chicken, this strategy has an inherent weakness: The threat not to abate is incredible. In economics, a threat is incredible if acting on a threat lowers the actor's payoff. Incredible threats are usually ineffective because other people regard them as bluffs. To be effective, people must believe that the party making the incredible threat is irrational.[32] Playing chicken thus requires overcoming an information obstacle and making others believe that you are irrational. While this possibility may arise some

[32] For example, an actor might make such a threat to stop potential competitors from entering the industry. In this case, the threat to impose liability costs on oneself in order to impose them on some else resembles predatory pricing. With predatory pricing, a monopolist threatens to price below the cost of production in order to prevent a competitor from entering the industry.

time, it is too unlikely to justify rejecting the rule of total liability for excessive harm as a practical policy.

Another strategic problem can arise when the injurers produce the same kind of goods and sell them in the same market. In these circumstances, injurers are competitors and each one may gain an advantage by increasing the other's costs. To illustrate, assume that the 5 actors discussed in Example 2 are competitors. Each actor realizes that by increasing harm above the target, he will increase the costs of his competitors. A firm might take advantage of this fact to preclude new competitors from entering the market. Instead of optimal pollution, the firms pursue entry-limiting pollution.

Similarly, a firm might use liability to engage in the pollution equivalent of predatory pricing. Predatory pricing refers to a situation where a firm temporarily prices below cost in order to drive a competitor out of the market, and then raises the price above cost. With a rule of total liability for excessive harm, a firm might temporarily create excessive harm in order to drive a competitor out of the market. After the competitor withdraws from the market, the remaining firm returns to creating optimal harm and avoiding liability.

The law has a long history of dealing with limit pricing and predatory pricing. The legal remedies are imperfect and the rule of total liability for excessive harm might sometimes aggravate these imperfections. Authorities might try to tailor liability to problems of imperfect competition.[33] Although these strategic problems are real, we do not consider them to be decisive in deciding whether or not to adopt our rule. One reason why these strategic problems are not decisive is that firms emitting the same pollutant often do not compete in product markets. When firms do not compete in product markets, the rule of total liability for excessive harm has no bearing on limit pricing or predatory pricing. Another reason is that when several injurers participate in the market, limit pricing or predatory pricing requires collusion among them. Besides the information

[33] The authorities might set different targets for different firms in order to take into account the risk of a big firm trying to defeat a small firm by increasing harms. To illustrate by Example 2, if the authorities detect a predatory behavior of one of the firms, it can set for the big firm a target of 125m, and 100m for the others, until the big firm stops behaving strategically. This possibility depends of course on the ability of the authority to observe such behaviors, which is not always easy.

obstacle to this kind of collusion, it is also illegal. The authorities already have legal remedies for limit pricing and predatory pricing.

V. Examples and Applications

To show that it is practical, we will describe some real and hypothetical situations where the rule of total liability for excessive harm could be applied to great advantage.

Fish Cages at Eilat

The gulf of Eilat in the Red Sea attracts many tourists to its coral reefs. As of August 2004, 70% of the coral reef in the Gulf of Eilat is dead or seriously damaged. The deterioration in the coral reef is attributed to the decline in the quality of water. Between 1997 and 2002, measurements of water quality have detected a rise in the concentration of nitrates, a decline in the pH of the water close to shore, the growth of sea-weed, and rise in the percentage of the organic substance in the bottom of the sea. Biochemical Oxygen Demand (BOD) in the water has reached the lowest level ever detected.

The decline in water quality is primarily due to fish cages. Approximately 2,500 ton of fish (primarily Sea Bream) are grown each year in the cages. On September 9, 2004 a group of international scientists (IET) published a report that concluded that the fish cages are responsible for over 80% of the non-natural nitrates in the Gulf. In addition to fish cages, other causes for decline in the quality of the water include discharge of sewage into the Gulf; the marina; oil leakages from boats, heavy metals, toxic organic substances, detergents, and TBT (a substance in the color that coats the bottom of boats); sand; and divers. However, the harm caused by all of these additional elements have been substantially reduces in recent years, and together they account for less than 20%.

The fish cages are operated by two main companies: Ardag, Ltd. and Dag-Suf, Ltd. The two companies operated on a temporary license that has expired, and now they continue to operate without proper licenses. In an attempt to close them, the Municipality of Eilat tried to stop their supply water, electricity, and telephone lines. In response, the two companies sued the municipality in 2003, alleging that the municipality has no jurisdiction over their operations in the sea. The district court of Be'er-Sheve rejected this claim and concluded that the municipality's actions were legal. Even so, the fish cages are still operating in the Gulf.

Consider how a liability rule might solve the problem. In this case, the total harm caused by the two companies is verifiable, whereas the individual contributions are unverifiable. Consequently, a rule of individual liability is impractical, whereas a rule of total liability is practical. A rule of total liability for excessive harm requires the authorities to set a target for total pollution. The authorities could start with a modest target and then raise it each year. The companies operating the fish cages would respond by increasing precaution or reducing activity level to avoid liability. Perhaps the companies would shift some of their operations from the sea to tanks or ponds on land. The legal target should continue to increase until the two companies prefer to pay for liability rather than reducing pollution any further, or until the companies close.

Industrial Pollution of the Kishon River

The final 7 kilometers of the Kishon River, where it flows into the Mediterranean Sea at Haifa, have been polluted by sewage runoff and industrial waste, especially from chemical plants, for over half a century. In 1994, the "Kishon River Authority" assumed responsibility to restore the river. Although some progress has been achieved, the Kishon River is still sufficiently polluted to prohibit fishing, swimming, or other water-sport activities in the river. These facts have especially caught the attention of the Israeli public because of the fate of an elite army squad. The squad trained in the polluted water and now has at least 88 documented cases of malignant tumors in its men. The incidence of cancer in this army unit far exceeds base rates. In this politicized atmosphere, the Kishon River Authority has committed to full ecological rehabilitation of the river by 2010.

According to the Israeli Ministry of Environment (2001) there are 8 main industrial sources of pollution, consisting of 3 petrochemical plants (Haifa refineries, Carmel Ulpinim, Gadiv) and 5 fertilizer plants (Haifa Chemicals, Dshanim, Gadot Biochemistry, and Frutarom). The industrial polluters discharge a variety of pollutants, especially the metals chromium, copper, mercury, and zinc. Measuring the extent of these metals in the river are easily measured, although the individual contributions of polluters upstream from the place of measurement are difficult to determine. In these circumstances, the Kishon River Authority could pursue its goals by applying the principle of total liability for excessive harm. For each metal, the small number of firms that discharge it would be totally liable for concentrations in the river that exceed the Kishon River Authority's targets.

Non-point source pollution

The Total Maximum Daily Load (TMDL) is the maximum amount of a pollutant that a water body can receive from all sources and still meet water quality standards. Section 303(d) of the U.S. Clean Water Act provides the EPA with the power to set TMDLs. The calculation must include a margin of safety to ensure that the water can be used for the purposes designated by the State. The calculation must also account for seasonal variation in water quality. Section 319 of the 1987 Act requires states to identify water bodies in which control of non-point source polluters is necessary, and to establish management programs for these water bodies.

The rule of total liability for excessive harm is practical when a small number of identifiable sources supply most of a particular pollutant. The rule is especially useful for non-point source pollution, such as runoff from agricultural and urban areas. While total NPS pollution is measurable, attribution of the individual contribution to NPS is seldom measurable. Where pollution from several sources eventually finds its way into a body of water, each polluter could be held liable for total harm caused by an excess of pollution above the TMDL. TMDLs provide targets suitable for a rule of total liability for excessive harm. Implementing liability involves attaching dollar values to harm from exceeding the TMDL for each pollutant.

Agricultural runoff is one form of non-point source pollution. For example, California's Regional Quality Control Board established TMDLs for water pollution caused by framers' irrigation tail water in Imperial Valley, California. The farmers were asked to install measures to control sediment in their runoff. The program helps identifying best management practices (BMPs) that can slow the flow of irrigation water and allow sediments to settle out before reaching the body of water.[34]

As another example, phosphorus runs off of farms into the Florida Everglades. The "Agricultural Privilege Tax" imposes a property tax increase on all farmers if basin-wide reductions in nutrient load into the Everglades do not meet statutory targets over time. Specifically, the statute requires the tax to begin at $24.89 per acre in 1996 and increase every four years to a maximum of $35 per acre from 2006 through 2014. However, the farmers in the designated area can escape the tax increase by exceeding an overall 25 percent basin-wide phosphorus reduction goal. Beginning in 1995-1996, phosphorus loadings will be compared to a baseline derived from loadings recorded from 1979-1988.[35]

Besides agricultural runoff, non-point source pollution occurs in urban areas from street runoff into storm sewers. Where storm sewers and sanitary sewers are combined, the runoff and the raw sewage pass into receiving waters when treatment systems become overloaded as a result of storms or thaws.

To show the scope of application of our rule, we now turn to some hypothetical examples.

Hypothetical Example of pollution by buses. A city has three large bus companies. The fleet of buses varies in age, design, and state of repair. City officials can determine with reasonable accuracy the amount of total pollution caused by buses, but not the amount of pollution caused by each of the three companies. Before remedial action, the buses emit 100 units of pollution. The City sets a target of reducing total pollution to 90 units.[36]

---

[34]An account of these facts is available in March 2005 on the internet at http://www.epa.gov/region9/water/nonpoint/nps-tmdl.pdf.

[35] See US Environmental Protection Agency, Non-point Source News-Notes, dated 10/96 and available online on the internet in 2005 at http://notes.tetratech-ffx.com/newsnotes.nsf/0/bff4df21f49ed6de8525666a0051923f?OpenDocument. We wish to thank Sandra Hoffman for this example and reference.

[36] An analogous situation was discussed in the case of *Michie v. Great Lakes Steel Division* 495 F.2d 213 (1974): defendants were several corporations that operated manufacturing plants in the United States, near the Canadian border. Plaintiffs were Canadian residents who filed a complaint in district court alleging that the combined, though non-conspiratorial, pollution caused by defendants' plants created a nuisance. The court held that the defendants may be jointly and severally liable as the nuisance produced a single,

To achieve the City's goal in this example, the City could impose a rule of total liability for excessive harm, which would hold each of the three bus companies liable for actual pollution exceeding the target of 90 units. This rule would give each of the three companies a strong incentive to reduce its own pollution and to collaborate with the other companies to help them reduce their pollution. The great advantage of the rule is that it creates efficient incentives for the three companies without requiring the City officials to inspect buses or enforce rules on their operation.

Now we turn to an example of hospital performance.

Hypothetical Example of Hospital Services. When Hospital A diagnoses melanoma, it refers the patient to Hospital B for treatment. The rate of death among patients diagnosed in hospital A and treated in hospital B is 20%. Experts using statistics determine that when diagnosis and treatment follow the best medical practices, the rate of death in the relevant population is 15%. The 5% excess in deaths e could result from tardy diagnosis by hospital A or deficient treatment by hospital B.

In this example, the hospital authority can impose a rule of total liability for excessive harm on hospital A and hospital B. Under such a rule, if the two hospitals continue to have a death rate of 20% and the optimal rate remains 15%, then each will pay for the excessive harm of 5%. Consequently, each hospital will have a strong incentive, individually and cooperatively, to adopt optimal practices and lower the death rate to 15%. Once the death rate falls to the optimum, the hospitals are no longer liable for the death of melanoma patients. (Note that in the case of hospitals, a participation tax is unnecessary to avoid excessive participation under the rule of total liability for excessive harm.)[37]

---

indivisible injury, where the division of liability among defendants was unascertainable. *See also H. Landers v. East Texas Salt Water Disposal Company et al.* 248 S.W.2d 731 (1952). The plaintiff alleged that each of the two defendants, one a saltwater disposal firm and the other an oil company, had independently polluted the plaintiff's lake, killing fish. The defendants were held jointly and severally liable.

[37] In our earlier analysis of pollution, we explained that when factories that abate optimally face no liability, a participation tax can make them internalize the social cost of their participating in the market. This problem of participation, however, does not arise in the preceding case of hospitals. When hospitals diagnose and cure melanoma at the optimal rate, their participation in the medical market does not cause the remaining melanoma deaths. Unlike polluting factories, there is no need for a participation tax on hospitals. If hospitals are held liable for harm that they did not cause, their profitability will fall, which will discourage participation. The rule of total liability for excessive harm avoids this problem by exempting hospitals that perform optimally from liability.

A potential problem with this liability rule is that the two hospitals might attempt to improve their performance by refusing to take patients whose survival prospects are below average. For example, hospital A might not admit patients who delay too long and come to the hospital with an advanced stage of melanoma. This is the same problem of adverse selection that afflicts private medical insurance markets. This problem diminishes or disappears in so far as hospitals must accept all patients in need of care.

Next we turn to accidents.

Hypothetical Example of Exploding Bottles. Company A supplies bottles to Company B who fills them with soda. Defective bottles supplied by A or defective filling of bottles by B can cause explosions that injure consumers.

In this example, the consumer protection agency could apply the rule of total liability for excessive harm. Under such a rule, the agency would collect statistics on the frequency of injuries to consumer of soda and determine the expected rate of injury for companies following the best practices. If the actual rate for company A and B exceeded the ideal rate, then the consumer protection agency would collect a fine from both companies. Thus the two firms would have a strong incentive to work together to reduce defects to the ideal level.

The next example that we give relates to cases where human behavior and nature inseparably combine to inflict injuries on many people.

Hypothetical Example of Radiation.[38] Several factories begin operating and emit carcinogenic radiation. In the area affected by radiation, the incidence of cancer increases by 25%, from 80 to 100 people each year. Distinguishing between the 20 victims of industry and the 100 victims of nature is impossible.[39]

Assume that the original rate of harm—80 victims—is the social optimum. Applying the rule of total liability for excessive harm to this example would make each factory liability for the harm suffered by all 20 cancer victims. The rule creates efficient

---

Sometimes there is a difference between optimal practices, and over-optimal practices, that can reduce harm even below the optimal level of harm. Still, one cannot argue that hospitals "caused" social harm when they took optimal practices (instead of over-optimal practices). To understand why, apply the "but for" causation test to hospital which takes the optimal level of care, and ask what would have been the social harm but for the participation of the hospital.

[38]See Porat & Stein, *supra* note, at p. 70.

[39] For a well-known case belonging to this category of cases and in which a settlement was reached, see In re "Agent Orange" Product Liability Litigation, 597 F. Supp. 740 (E.D.N.Y. 1984), *aff'd,* 818 F. 2d 145 (2d Cir. 1987).

incentives for the factories to eliminate deaths from industrial radiation. Damages could be paid to the state or to the 100 victims of cancer.

We conclude this section with an example of how the rule of total liability for excessive harm can help solve the "Tragedy of the Common."

<u>Hypothetical Example of the "Tragedy of the Commons"</u>. Five municipalities around a lake regulate fishing by its citizens. The Lake Authority is concerned that the municipalities will allow too much fishing and deplete the stock of fish. Monitoring each municipality is costly.

The three municipalities in this example potentially face a "tragedy of the commons." All of them benefit as a group from preserving the optimal stock of fish. However, each municipality benefits as an individual from fishing more than its share and free-riding on the restraint of the others. To solve the problem, the Lake Authority can adopt this rule of total liability for excessive harm: When the stock of fish falls below a certain target, each of the three municipalities should pay a tax. The tax rate should reflect the social harm caused by the shortfall in the stock of fish. The municipalities should support this policy by the Lake Authority because it averts the tragedy of the commons at low administrative costs.

We have explained that the municipalities should support the policy of total liability excessive harm imposed on them by the Lake Authority. For the same reason, if there were no Lake Authority, the municipalities should reach this same arrangement by contract. The contract would specify that each of them must pay for excessive total harm, and the payment should go to a third party such as a charity.

VI. Conclusion

In the last century, the rule of strict liability for consumer product injuries displaced the rule of negligence. Problems of proof compelled the change. In our view, the same consideration will eventually compel replacing individual liability for certain kinds of harm with total liability for excessive harm. As we have explained, the rule is practical under three conditions: (i) total harm is verifiable, (ii) optimal total harm is calculable, and (iii) the number of injurers is not too large. When these conditions are met and individualized liability, taxes, fines, or transferable rights are too costly to administer, we recommend adopting the rule of total liability for excessive harm.

Moralists might reject this recommendation because it imposes "collective punishment." As we have explained, once the system reaches equilibrium, no one actually pays for the harm caused by another.[40] On the path to equilibrium, however, actors could find themselves paying for harms caused by others. Or errors or strategic behavior could make actors pay for harms caused by others. Even in these cases, however, the excessive harm caused by everyone is usually less than the individual harm caused by each actor. The rule of total liability for excessive harm, consequently, will usually result in lower damages than the rule of strict liability for individual harm. When each actor pays less than the individual harm that he caused, the situation, he has little reason to complain of "collective punishment."

The fact that the total liability for excessive harm rule creates socially optimal incentives should make it attractive to people who want to benefit the public. The fact that each injurer's liability equals zero in equilibrium should make the rule more attractive to injurers than more burdensome alternatives. In order for peole to be attracted to the rule, however, they must understand its consequences. As this paper shows, some consequences are counter-intuitive. The difficulty that most people have in understanding the effects of the rule of total liability for excessive harm constitutes the largest obstacle to its acceptance.

[40] The argument for the rule's fairness resembles the utilitarian justification of an effective deterrent: An "effective" deterrent is fair because it does not have to be used. Utilitarian and deontological traditions disagree about whether a very harsh penalty that perfectly deters and never require use should be praised for its good consequences or condemned for its excessive threat. For a recent contribution to this debate that favors the utilitarian tradition, see L. Kaplow and S. Shavell, "Fairness versus Welfare" 114 *Harvard L. Rev*. 961-1388 (2001). For environmental law application, *see* Shi-Ling Hsu "Fairness Versus Efficiency in Environmental Law" 31 *Ecology L.Q.* 303 (2004) (arguing for more economics and more efficiency-thinking in environmental law).

Mathematical Appendix

Definitions

n=number of potential participants
m=number of actual participants, where $m \underline{<} n$.
k^i=actor i's fixed cost of participating
K^m= total fixed cost of participating by actors 1,2,…,m.
x^i_j = input j by actor i
$\underline{x}^i$ = vector of inputs by actor i, one of which is precaution x^i.
$\underline{x}$= vector of inputs by all actors 1, 2,…n
$\underline{p}_j$= price of input j
$\underline{p}$= vector of prices of inputs
y^i= output by actor i (also called "activity level")
$\underline{y}$= vector of outputs by all actors
q_i= price of i's output
$\underline{q}$= vector of market prices of outputs
h^i= harm caused by actor i
H=total social harm
$H^{)i(}$=total harm that would result if actor i were not participating
l^i=i's liability
t^i=i's lump sum participation tax
V=social welfare
* indicates a socially optimal value.

Functions

$K^m = k^1 + k^2 + \ldots + k^m$=total cost of participating by m actors
$y^i = y^i(\underline{x}^i)$ production function of actor i
$0 = y^i = \underline{x}^i$ for $i \underline{>} m+1$ no activity or precaution by non-participants
$H=H(\underline{y};\underline{x})$ total harm
$H^{)i(}=H(\underline{y};\underline{x}) - H(y^1,y^2,\ldots,y^{i-1},0,,y^{i+1},\ldots,y^m;\underline{x}^1,\underline{x}^2,\ldots \underline{x}^{i-1},0,\underline{x}^{i+1},\ldots,\underline{x}^m)$
$h^i=H- H^{)i(}$
$V=\underline{qy} - \underline{px} - H(\underline{y}, \underline{x}) - K^m$ social welfare function.

Assume that potential participants 1,2,…,n are uniquely arranged in order from highest to lowest contributors to social welfare. Consequently, when all actors who participate do so at the socially optimal inputs, social welfare falls more when actor i stops participating than when actor i+1 stops participating, for all i.

Social optimum

Maximize social welfare:
max $\quad \underline{qy} - \underline{px} - H(\underline{y};\underline{x}) - K^m$
xym
subject to

$y^i = y^i(\underline{x}^i)$ all i
$0 = y^i = \underline{x}^i$ for $i \geq m+1$.

First order conditions for optimal activity level and precaution by all m participants:
$q_i - H_{yi} + \lambda \leq 0$ optimal activity level y^{i*} for i=1,2,..,m.
$-p_j - H_{xij} - \lambda\, y^i_{xij} \leq 0$ optimal precaution $\underline{x}^i_j{}^*$ for i=1,2,..,m and j=1,2,..,m.
Combining the preceding conditions yields
$$q_i y_{xij} - p_j - H_{yi} y^i_{xij} - H_{xij} \leq 0 \quad \text{for all i,j} \tag{1}$$

Conditions for number of participants m to be optimal:
$$q_i y^{i*} - \underline{px}^{i*} - h^{*i} - k^i \geq 0 \text{ for i=1,2,..,m} \tag{2}$$
$$< 0 \text{ for i=m+1, m+2,…,n.}$$

Individual Rationality

Assume that each actor i responds to prices, liability, and taxes, but does not anticipate how his behavior might influence the behavior of others (zero conjectural variations). i maximizes his profits:
$$\max_{\underline{x}^i y^i} q_i y^i - \underline{px}^i - l^i - t^i$$
subject to
$y^i = y^i(\underline{x}^i)$.
First order conditions:
$q^i - l^i_{yi} + \lambda^i \leq 0$ individually optimal activity level y^{i+}
$-\underline{p}_{xij} - l^i_{xijj} - \lambda^i y_{xij} \leq 0$ individually optimal precaution $\underline{x}^{i+}_j$ for all j
Combining conditions yields
$$q^i y_{xij} - \underline{p}_{xij} - l^i_{yi} y_{xij} - l^i_{xij} \leq 0. \tag{1'}$$

Condition for i's participation (non-negative average net revenues):
$$q_i y^{i+} - \underline{px}^{i+} - l^{i+} - t^i - k^i \geq 0. \tag{2'}$$

Propositions – proofs are interpretations of the conditions for social and individual optima

We prove the efficiency or inefficiency of equilibria that exist, but we do not prove the existence of equilibria. The propositions are interpretations of the conditions for social and individual optimization.

Proposition 1. Strict liability. Assume that m actors participate in an activity with unverifiable activity levels and unverifiable precautions that cause external harm H. Assume that individual harm h^i is verifiable for all m participants. Strict liability of injurer i for the harm h^i creates socially optimal incentives with respect to i's precaution and activity level.

Proof:

By assumption, i’s liability equals the harm i caused, $l^i=h^i$. By Definition, l^i= H-$H^{)i(}$.

Equation (1`) for individual rationality thus reduces to the condition for socially optimal precaution and activity level: $q_i y_{xij} - p_j - H_{yi} y^i_{xij} - H_{xij} \leq 0$.

Proposition 2. Negligence. Assume that m actors participate in an activity with verifiable precautions x^i_p that cause external harm H. Assume that individual harm h^i is verifiable for all m participants. Assume that law imposes a legal standard of care at the social optimum, x^{i*}_p. If an injurer’s case falls below the legal standard x^{i*}_p, then injurer is liable for actual harm that would have been avoided if his care had equaled the legal standard. Otherwise injurer is not liable. i’s precautions will be efficient, and i’s activity level will be inefficient.

Proof:

1. Assume that actual precaution $x_{i\cdot}$ is epsilon below the legal standard, which is the social optimum by assumption. Consequently, the individual is liable for the actual harm that he causes. His costs are the same as under strict liability, so, by Proposition 1, costs are minimized by setting precaution and activity level at the social optimum, and thus he increases his precaution by epsilon and it equals the social optimum.

2. When precaution equals the social optimum, liability falls to zero. Now equation (1`) for individual rationality reduces to the following for all variables except precaution:

$q_i y_{xij} - p_j \leq 0$ for all inputs j except those indicating precaution.

This condition does not coincide with the social optimum except by chance.

Proposition 3. Excessive harm. Assume that m actors participate in an activity with unverifiable activity levels and unverifiable precautions that cause verifiable external harm H. Assume the individual harm h^i and the optimal harm h^{i*} are verifiable. Individual liability for excessive harm (h^i-h^{i*}) gives the injurer socially optimal incentives with respect to his precaution and activity level.

Proof:

1. Assume that actual harm h^i is above the legal standard h^{i*}. Consequently, injurer’s liability for excessive harm (h^i-h^{i*}) is identical to injurer’s liability under a rule of strict liability except for the constant h^{i*}. First order conditions are invariant with respect to changing the maximand by a constant. Consequently, the proof for Proposition 1 implies that injurer will lower h^i to h^{i*}.

2. Assume that actual harm h^i is below the legal standard h^{i*}. Consequently, the injurer’s liability is zero. Therefore the injurer will lower his costs by reducing precaution and increasing the activity level until he raises h^i to h^{i*}.

Proposition 4. Strict total liability. Assume that m actors participate in an activity with unverifiable activity levels and unverifiable precautions that cause verifiable external harm H. Assume that transaction costs prevent collusion among participants. Liability for total harm H gives each participant socially optimal incentives with respect to precautions and activity level.

Proof: By assumption, individual i's liability equals total harm: $l^i = H$. Consequently, condition (1) for socially optimal activity level and precaution is the same as condition (1`) for individual rationality.

Proposition 5. Total liability for excessive harm. Assume that m actors participate in an activity with unverifiable activity levels and unverifiable precautions. Assume that actual total harm H and optimal total harm H* are verifiable. Liability for excessive harm H-H* gives each injurer efficient incentives with respect to precautions and activity level.

Proof:

1. Assume that actual harm H is above the legal standard H*. Consequently, injurer's liability for excessive harm (H-H*) is identical to injurer's liability under a rule of strict total liability except for the constant H*. First order conditions are invariant with respect to changing the maximand by a constant. Consequently, the proof for Proposition 1 also proves that injurer will increase his payoff by decreasing activity and increasing precaution until H equals H*.
2. Assume that actual harm H is below the legal standard H*. Consequently, the injurer's liability is zero. Therefore the injurer will increase his payoff by increasing activity and decreasing precaution until H equals H*.

Proposition 6. Proportionate liability. Assume that m actors participate in an activity with unverifiable activity levels and unverifiable precautions that cause verifiable external harm H. Assume that transaction costs prevent collusion among participants. Liability for proportionate harm (H/m) gives each injurer deficient incentives with respect to precautions and activity level.

Proof:

1. The condition (1) for social optimal activity level and precaution reduces is $q_i y_{xij} - p_j - H^i_{yi} y_{xij} - H^i_{xij} \leq 0$.
2. The assumption that liability l^i equals H/m implies that equation (1`) for individual rationality reduces to $q^i y_{xij} - \underline{p}_{xij} - (H^i_{yi} y_{xij} - H^i_{xij})/m \leq 0$.
3. Thus individual rationality results in sub-optimal precaution and activity level except by chance.

Proposition 7: Optimal participation. Assume that n actors potentially participate in an activity. Assume that participants face liability that induces socially optimal precaution and activity level. Assume that external harm H increases with more participation. Incentives for an optimal number of the n actors to participate are achieved if each actor i who participates pays a lump sum tax equal to the harm h^{*i} caused by participating at optimal level of activity and precaution minus the liability l^{*i}.

Proof:

1. Incentives for participation are socially optimal when equal (2`) is identical to the condition for individual participation (2). Setting these equations equal to each other yields $q_i y^{i*} - \underline{px}^{i*} - h^{*i} - k^i = q_i y^{i+} - \underline{px}^{i+} - l^{i+} - t^i - k^i$.

2. By assumption, injurers face liability that induces socially optimal precaution and activity level, so $\underline{x}^{i}*=\underline{x}^{i+}$ and $y^{i}*= y^{i+}$.
3. Substituting "2" into "1" yields $t^{i} = h*^{i} - l^{i}$.

<u>Proposition 8. Total liability for excessive harm with random additive error</u>. Assume that m risk-neutral actors participate in an activity with unverifiable activity levels and unverifiable precautions. Assume that actual total harm H and optimal total harm H* are verifiable with additive error ε. When H+ε>H*, each injurer is totally liable for H-H*+ε. Otherwise each injurer is not liable.
(i). If the expected error is unbiased (E(ε)=0), then the injurer has socially efficient incentives with respect to precautions and activity level.
(ii). If the expected error is biased towards a legal standard that is too low (E(ε)<0), then the injurer has incentives for too little precaution and too much activity.
(iii). If the expected error is biased towards a legal standard that is too high (E(ε)>0), then the injurer has incentives to take optimal precaution and activity (but optimal incentives are vulnerable to collusion).
<u>Proof</u>:

1. Consider two cases. First, consider the case where the injurer expects to be no liable. Thus assume that H is less than H*- E(ε). Injurer will increase his payoff by increasing activity and decreasing precaution until he becomes liable, which occurs when H equals H*- E(ε). Thus injurer will set H equal to H* if E(ε) is zero; injurer will set H higher than H* if E(ε) is negative; injurer will set H lower than H* if E(ε) positive.
2. Second, consider the case where the injurer expects to be liable. Thus assume that H is greater than H*- E(ε) and injurer expects to be liable for H-H*+ E(ε). Minimizing injurer's total costs with liability H-H*+ E(ε) is identical to minimizing total costs with liability H-H* but for the constant E(ε). First order conditions are invariant with respect to changing the maximand by a constant. Consequently, the proof for Proposition 5 also proves that injurer will set H equal to H*.
3. If the expected error is unbiased (E(ε)=0), then step 1 and step 2 indicate that injurer will set H equal to H*, which proves (i).
4. If the expected error is biased towards a legal standard that is too low (E(ε)<0), then injurer will set H above H* and escape liability as indicated in step 1. Since injurer already expects not to be liable, injurer would gain nothing from lowering H to H* as in step 2.
5. If the expected error is biased towards a legal standard that is too high (E(ε)>0),

then injurer will set H equal to H* as indicated in step 2.