Should Products Liability Be Based on Hindsight?

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In designing and marketing new products, manufacturers face uncertainty regarding the harmful nature of their products. If harm occurs due to a defective design, liability is imposed on manufacturers whenever the design of the product is determined to be unreasonably dangerous. In assessing the reasonableness of a design, courts often—although the doctrine is not settled—admit information which was acquired throughout the actual usage of the product, information that often was not scientifically available at the time of production. Asbestos litigation is a prominent example of this controversial practice. This article examines the incentive effects of such hindsight. It demonstrates that the utilization of information that is available ex post but was not available ex ante may lead to adverse incentive effects in (1) installing safety devices in products; (2) developing technologies that are less risky; and (3) investing in research that can identify the risks in advance. Yet such hindsight unambiguously improves incentives to make safety adjustments subsequent to the distribution of the product. While the overall welfare effect of hindsight is ambiguous, this article identifies particular circumstances in which hindsight is likely to reduce social welfare. The analysis offers partial justification for some controversial stances taken by the Restatement (Third) of Products Liability.

1. Introduction

Almost all products designed and developed by manufacturers subject their users to risks of injury and harm. Under the doctrine of strict liability, manufacturers are liable for these injuries regardless of the intensity of their prevention efforts. Thus if a product causes harm because it is in a condition different from its design, due to, say, a defect in the production process, the manufacturer

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is liable for the damages to the consumer-victim, no matter how prudent the manufacturer was in monitoring production.[1]

While strict liability is the predominant rule governing manufacturing defects, it does not traditionally apply with respect to defects in the design of a product. Manufacturers' liability for harms arising from products that are functionally sound and are operating as designed, but nevertheless carry dangerous features, is based traditionally on negligence. As § 2(b) of the Restatement (Third) of Products Liability maintains, only when the foreseeable risks the product creates "could have been reduced ... by the adoption of a reasonable alternative design" will the manufacturer be found liable.[2] In this spirit, courts apply various tests to determine whether or not, in designing a product, the manufacturer acted reasonably. Widely accepted are the "risk-benefit" or "risk-utility" tests (comparing the product's risk to the cost of prevention or to the product's value) and the "consumer expectation" test (examining whether the product was more dangerous than an ordinary consumer would have expected).[3] Under either test, the plaintiff has a negligence hurdle to clear.

When the negligence regime operates under perfect conditions, it is widely believed to provide optimal incentives for manufacturers to invest in product design (Landes and Posner, 1987:291–93). But in governing the incentives for the design of safe products, the negligence regime rarely performs under perfect conditions. In ordinary situations, manufacturers who design products have limited information about the product's future risks. Many of the defects are revealed only after extensive use of these products. The different types of injuries and side effects, as well as their true frequency, can be difficult or costly to anticipate at the early stages of design, testing, production, or sample marketing. The long-term exposure harms from asbestos products is a well-documented example of a product risk whose full magnitude was not known for a great many years.[4] Similarly, the design of commercial drugs is inherently shadowed by the problem of unanticipated harmful side effects.

Courts and legal scholars have had tough times dealing with this problem of unanticipated risks and the appropriate scope of liability for them. In the vast body of literature that has emerged in the past generation, the problem of unanticipated risks is often labeled as *the most vexing, agitated, and controversial issue in the entire field of products liability law.* The debate has recently climaxed with the emergence of the new Restatement (Third) of Products Liability.[5] The debate surrounds the question of which fragments of the experience gained by the continuous use of a product should be utilized to eval-

1. See § 2(a) of the Restatement (Third) of Products Liability (Tentative Draft, 1995).

2. See, e.g., *Prentis v. Yale Manufacturing Co.*, 365 N.W.2d 176 (Mich. 1985); *Suter v. San Angelo Foundry & Machine Co.*, 406 A.2d 140 (N.J. 1979); and Shapo (1987:ch. 8, 9).

3. For the risk-benefit and risk-utility tests, see, e.g., *Roach v. Kononen*, 525 P.2d 125 (Ore. 1974). For the consumer expectations test see Restatement (Second) of Torts § 402A comment *i*, and *Barker v. Lull Engineering Co.*, 573 P.2d 443, 454 (Cal. 1978).

4. See, e.g., *Beshada v. Johns-Manville Products*, 447 A.2d 539 (N.J. 1982).

5. For a recent symposium regarding the new Restatement's approach to the problem of unanticipated risks, see *Chicago-Kent Law Review* (1996).

uate liability and which should be overlooked. To what standard of knowledge should the manufacturer be held? Should, for example, a manufacturer of a substance that is newly discovered to be carcinogenic bear the costs of that previously unknown hazard?

In surveying the views on this issue one can quickly identify two opposing approaches.[6] The first approach, which appears to reign in important cases decided by U.S. courts, can be labeled the "hindsight" regime. According to this approach, a product's design is negligently defective if the risks involved in its use, *as they are known at the time of trial*, outweigh the costs of avoiding these risks.[7] Thus, into the evaluation of the reasonableness of the design enters information that was not available to the firm during the time of the product's design, perhaps even information that had not been scientifically attainable, but which subsequently became known through the use or misuse of the product.

The second approach, the "state-of-the-art" regime, does not attribute to the manufacturer knowledge which was not available at the time of the production. According to this approach, a manufacturer is only held to know what courts assess to have been the scientific state of the art at the time the manufacturer designed, produced, or marketed the product. If, based strictly on information that was available ex ante, the product is unreasonably dangerous, liability will be imposed.[8]

Thus the main question that will be examined in this article is how much of the information which is known ex post but was not available to the manufacturer ex ante should be utilized in determining the reasonableness of the product's design. While this question has received numerous treatments in legal scholarship, it has not yet been thoroughly addressed within the frame-

6. Wade (1983) offers a survey of the various possible approaches to the problem.

7. For case applications, see *Beshada v. Johns-Manville Corp.*, 447 A.2d 539 (N.J. 1982); *Green v. American Tobacco Co.*, 154 So.2d 169 (1963); *Ross v. Up-Right Inc.* 402 F.2d 943, 946 (5th Cir. 1968); *Helene Curtis Industries, Inc. v. Pruitt*, 385 F.2d 841, 850 (5th Cir. 1967); *Phillips v. Kimwood Machine Co.*, 525 P.2d 1033 (Ore. 1974). This approach is embraced by the Model Uniform Products Liability Act § 107. See also Keeton (1969, 1970). In the language of one court:

> [Under the hindsight regime] it is not the conduct of the manufacturer or designer which is primarily in question, but rather the quality of the end result; the product is the focus of the inquiry. The quality of the product may be measured, not only by the information available to the manufacturer at the time of design, but also by the information available to the trier of fact at the time of trial. [The question is] whether a reasonable manufacturer would continue to market his product in the same condition as he sold it to the plaintiff with knowledge of the potential dangerous consequences.
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> (*Dart v. Wiebe Mfg. Inc.*, 709 P.2d 876, 881 (Ariz. 1985).)

8. See Wade (1983). Some courts have adopted this approach, e.g., *Murphy v. Owens-Illinois, Inc*, 779 F.2d 340, 342-3 (6th Cir. 1985). Several U.S. states have enacted statutes expressly providing for the state-of-the-art defense. See, e.g., Ariz. Rev. Stat. Ann. § 12-683 (Supp. 1980); N.H. Rev. Stat. Ann. § 5507-D:4 (Supp. 1979). Comment *k* of § 402A of Restatement (Second) of Torts (1965) has been interpreted by some to advocate the state-of-the-art test for pharmaceutical products. See V. Schwartz (1985). Most importantly, the state-of-the-art test was advocated by the reporters of the new Restatement (Third) of Products Liability (see Henderson and Twerski, 1991) and appears to have been incorporated into § 2(b) of the Restatement.

work of incentive theory. Courts and commentators have often speculated as to the incentive effects of the alternative rules, but—as will be shown in this article—their intuitions are not always valid. A formal economic analysis is timely, particularly now that the new Restatement of Products Liability takes a stand on this issue and is stirring a fierce legal debate (see, e.g., Bogus, 1996; Page, 1996).

In analyzing this question, the article will compare the incentive effects with respect to several care activities that manufacturers typically perform. First, the analysis will consider the manufacturer's incentives to invest in safety measures accompanying the product to reduce the harm given the known distribution of risks. Second, the analysis will examine the incentives to change the scientific state of the art—that is, to develop new, safer technologies. Third, the analysis will explore the incentives to invest in refitting a product and reducing its harm after it has already been distributed. Lastly, the analysis will examine the firm's incentives to become more informed about forthcoming hazards.

The main results of the article are as follows. It is shown, following the work of Shavell (1987, 1992) and others, that hindsight distorts incentives to take care against the known distribution of risks. Better incentives are provided under the state-of-the-art regime. It is well recognized that a party facing a random standard of care may be motivated to take excessive precaution as a safeguard against liability. What is less familiar is that the same party may also choose to take too little care, since he is concerned about harm reduction only with respect to injuries for which he will be considered negligent. Further, neither liability regime induces socially optimal investment in developing new technologies. However, contrary to a common conjecture, the hindsight regime does not necessarily lead manufacturers to invest less in technological improvements. True, hindsight does make the introduction of a next generation technology a more risky financial adventure, but it also makes the current generation technology more costly for manufacturers. In addition, hindsight can be expected to lead to more postmarketing investment in safety, that is, efforts to reduce harm after the product has already been marketed. This is due to the fact that under hindsight manufacturers will be liable for harms as they are revealed, and thus be driven to take costly measures to repair distributed products so as to reduce these harms. Lastly, both regimes lead manufacturers to invest excessively ex ante in becoming informed about the risk. Plagued by the distortion that negligence regimes generally create with respect to the value of information (Kaplow and Shavell, 1992), both regimes provide manufacturers with a private benefit from information that exceeds its social value. But in contrast to intuitive conjectures, hindsight may not necessarily create the stronger incentive to become informed.

While the article does not reach a determinate recommendation as to the superiority of one regime or another, it offers some insight as to the desirable path the law should take. It demonstrates how particular objectives regarding product safety and particular incentives for manufacturers can be promoted by the choice of a liability approach. It suggests that the products liability law of design defects should probably not be uniform across all products and industries, but should instead be product specific, tailored to promote social interests as they vary across industries. The article offers insights as to the desirable rule across various industries and products.

The article is organized as follows. Section 2 develops the framework of the formal model. Section 3 analyzes the incentives to install safety devices. Section 4 examines the incentives to develop a safer technology. Section 5 examines the incentives to engage in postmarketing safety efforts. Section 6 looks at the manufacturer's incentives to acquire information about product hazards. Section 7 offers unifying insights and concluding remarks.

2. Framework of Analysis

2.1 The Sequence of Events

A manufacturer designs a product for sale to consumers. Since the product may cause harm to consumers, the manufacturer can install costly safety features in the product to reduce its risks. For simplification it is assumed that manufacturers and consumers are risk neutral, and that consumers cannot take measures to reduce expected harm.

Let x denote the manufacturer's investment in safety features. Let H denote the harm from the product. It is assumed that the harm is random and depends on x and on θ, a random variable denoting idiosyncratic risk. Thus denote the random harm by $H(x, \theta)$. It is assumed to be continuously differentiable, with $H_x < 0$, $H_{xx} > 0$ (diminishing marginal returns to safety measures) and $H_\theta > 0$ (the expected harm increases with θ). It is plausible to further assume that $H_{x\theta} < 0$, that is, as the product becomes more risky, the marginal return to investment in safety increases. For example, the harm reduction benefit from strengthening a car's bumpers (higher x) increases as the car is more likely to be in an accident due to factors incorporated in θ such as highway quality or random mechanical malfunctions. It is assumed that θ is distributed between $[0,1]$ according to a continuous and twice differentiable distribution function $F(\theta)$, with density $f(\theta)$.

This framework is sufficiently general to capture many uncertainties in the product design stage. For example, θ may denote the random magnitude of harm that a consumer of a new drug will suffer as a result of application of the drug, while x may stand for the manufacturer's efforts to reduce the likelihood or adequately warn against such a reaction. Or θ may denote the unknown likelihood that a car will lose its brakes and x may stand for safety features installed to reduce the magnitude of harm (e.g., airbag).[9]

In addition to setting x, it is assumed that the manufacturer may take several other actions. First, before setting x, the manufacturer might invest a discrete amount c to develop a new, safer technology. This investment in R&D shifts the distribution of θ from $F(\theta)$ to $G(\theta)$ in a manner that makes lower values of θ more likely (technically it will be assumed that $G(\theta)$ is first-order stochas-

9. If we denote the probability of harm by p and the magnitude of harm by h, in the first example we have $H(x,\theta) = p(x)h(\theta)$; in the second example we have either $H(x,\theta) = p(\theta)h(x)$ or $H(x,\theta) = ph(x,\theta)$.

tically dominated by $F(\theta)$. This investment, like the investment in x, serves to reduce the expected harm. Yet unlike the investment in x, it is often not readily observed by courts. Determining whether the investment in technology was negligent is more complex than scrutinizing the level of care. It requires knowledge of alternative technologies, the distribution of harms under hypothetical technologies, as well as an ability to monitor the firm's R&D operations, usually performed in secret. (For example, in defective drug cases, courts are normally reluctant to compare a drug's substance to alternative compounds for the same illness, and instead restrict themselves to examining care and warning practices with respect to the given substance.) Thus for simplicity the analysis will follow the assumption that c is not adjudicable and will examine separately the decisions to invest x and c.

Also, after choosing technology but before setting x, the manufacturer might also invest to become informed about the actual θ. For example, a children's toy manufacturer might spend more on testing the components to reveal weaknesses and dangers, and to know how to instruct or warn for safe use. It is assumed that the manufacturer might spend a discrete amount k and acquire perfect information about θ, enabling him to select a care level x which could depend on θ.

In addition, as the product is being distributed with a given safety level x but before harm occurs in full, the manufacturer might gain private information about θ and invest further in risk-specific care measures. For example, automakers might issue recalls to repair defects of which they become aware as injuries begin to accumulate. That is, in situations in which the full magnitude of harm from the product materializes and becomes known gradually over a period of time, care measures may be added throughout this period to reduce some of the remaining harm. If courts cannot scrutinize these efforts directly, it will be explored how their scrutiny of the levels of x will affect the manufacturer's incentives to take these postmarketing, risk-specific measures. Specifically the manufacturer might invest $y \geq 0$ in postsale safety, so that the random harm can be denoted as $H(x, y, \theta)$.

The timing of the model is summarized in Figure 1. At time 0 the manufacturer designs the product's technology and, knowing the distribution of risks it entails, chooses whether or not to become informed about θ. At time 1 the manufacturer sets x. At time 2 the product is distributed to the consumers. At time 3 the value of θ realizes. It may or may not, as will be explained in Section 5, become known to the manufacturer; if it does, additional safety y can be invested at that time. At time 4 the random harm H materializes. At time 5 a costless trial can take place.

2.2 Information

It is assumed that courts can perfectly verify the manufacturer's level of care x. In addition, courts know both θ and its ex ante distribution, whether it is $F(\theta)$ or $G(\theta)$. While this last assumption—that courts can determine ex post what had been the ex ante distribution of risks—is not always realistic, it is made to reflect a practice under which courts do, in fact, inquire about what firms knew

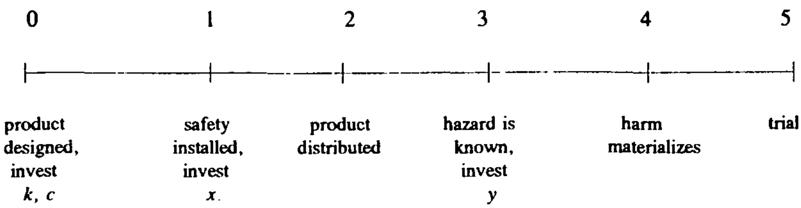

Figure 1.

or could have known. This practice is indicated by many courts' readiness to apply the state-of-the-art defense. The fact that this inquiry may be costly will be discussed in the concluding remarks.

In addition, it is assumed that courts do not know whether or not the manufacturer knew θ ex ante (whether or not he invested k), and that courts cannot verify the level of postmarketing care, y, that the manufacturer has set. The logic underlying these verifiability assumptions will be explained and become apparent in the relevant sections.

It is also assumed that consumers have no information about the product's harmfulness—that is, the decision to purchase a product is independent of the safety-related actions taken by the firm. Also, consumers do not know whether or not liability will be imposed in case harm occurs, and what the manufacturer did to reduce the risk. A warranty is not attached to the product, and there is no competition-induced adjustment of price to safety level. Thus neither the price nor the quantity sold by the firm in the market depend on its care decisions. These assumptions are made in order to abstract from market discipline effects and to focus strictly on the impact of liability rules. Finally, it is assumed that firms know the structure of the problem. While they do not know θ (unless they invest k), they know its distribution and the different actions that may reduce the product's risk.

2.3 The Liability Rule

The litigation stage (time 5) is governed by the negligence rule (Restatement (Third) of Products Liability, § 2(b)). The court sets a standard of due care for the manufacturer $\bar{x}$ and assigns liability to the manufacturer if and only if $x < \bar{x}$. In establishing the standard of care $\bar{x}$, the court may adopt one of two approaches:

(i) Hindsight. The court takes into account all the information about the risk which becomes available by the time of the trial, including information that the manufacturer did not have ex ante. The court sets a standard that depends on the realization of θ. This standard $x^*(\theta)$ is the solution to the ex post optimization problem:

$$\min_{x}[x + H(x, \theta)] \tag{1}$$

(ii) State of the art. The court takes into account only the information that was available to the manufacturer at the time of production. It ignores the realization of θ, and instead uses only the information about $F(\theta)$. The court sets $\bar{x} = x^*$, the solution to the ex ante optimization problem:

$$\min_{x} \left[x + \int_{o}^{1} H(x, \theta) dF(\theta) \right] \tag{2}$$

It should be conceded that since the state-of-the-art rule requires courts to know $F(\theta)$, and since this information may be difficult for courts to obtain, the regime that sets a standard of x^* might not be feasible. In such a case, it is studied here as an ideal, not as an accurate description of adjudicative practice.

The next four sections explore the incentives to spend x, c, y, and k under the two liability approaches, hindsight versus state of the art.

3. Incentives to Install Safety Devices

This section presents the distortion that the hindsight regime creates with respect to incentives to invest in care. Most of the results in this section have appeared previously in a general formulation. The aim here is to briefly put these results in the specific context of the debate over hindsight, to demonstrate some misconceptions appearing in the legal literature, and to set the stage for subsequent analysis of other production incentives.

3.1 Doctrinal Background

Courts and legal scholars have speculated extensively on the effects of holding firms liable for injuries that arise from the normal use of the product but were unanticipated at the time of the product's design. The prominent view arising from case law is that hindsight "would induce providers of services to invest in safety, leading to greater protection of their customers and reduced accident costs,"[10] and that it would "create significant safety incentives. Manufacturers would operate under a powerful and unremitting incentive to adopt all appropriate safety devices" (G. Schwartz, 1979:443, 484). It is conceded that hindsight introduces uncertainty, but claimed that "uncertainty in the law has salutary accident-reducing effects on manufacturer conduct" (Shapo, 1987:9.3).

Before exploring these conjectures, it is helpful to distinguish between two related claims made in the legal literature. Legal commentators argued that while inducing manufacturers to invest more in safety, hindsight might also inhibit socially desirable developments of new products (V. Schwartz, 1985:1141; Wade, 1983:755). This last claim, regarding the "activity level" effect of hindsight, is not valid. True, the manufacturer might face an increased scope of liability, but at worst the inflated liability could lead the manufacturer to ignore the standards and bear the full social cost of the product, as under strict liability.

10. *Michalko v. Cooke Color & Chem. Corp.*, 451 A.2d 179, 186 (N.J. 1982). See also *Beshada v. Johns-Manville Corp.*, 447 A.2d 539, 547 (N.J. 1982); Wade (1983:754).

In such a case, the manufacturer will take optimal care, which minimizes the expected social cost of harm and care. Thus the "crushing" effect of liability on production, if it occurs, is a desirable by-product. Such an effect would occur only if the product causes more social harm than benefit. Hence when we compare two negligence regimes, the only distortions that can potentially arise are with respect to care levels and excessive production. The expressed concern that desirable production activities will also be deterred is generally unfounded.[11]

3.2 Incentives to Invest in Safety Under the State-of-the-Art Regime

Under this regime, the court sets the ex ante efficient standard x^*, utilizing only the information about $F(\theta)$. It is well known that such a regime would lead the manufacturer to invest x^* in safety. Calabresi and Klevorick (1985) were the first to point out that such an "ex ante Learned Hand test," as they labeled it, leads to optimal care. The manufacturer can anticipate x^*, satisfy it, and avoid the costlier expected liability. A formal proof of this result appears in Shavell (1992).

3.3 Incentives to Invest in Safety Under the Hindsight Regime

Under this regime, the court observes θ and sets the ex post efficient standard $x^*(\theta)$. Such a regime distorts the manufacturer's incentives. The insight, which was originally made by Calfee and Craswell (1984) and Calabresi and Klevorick (1985) and proved by Shavell (1987:93), can be explained as follows. Consider the manufacturer's optimization problem. For every level of x he sets, there is a critical level of θ, denoted by $\hat{\theta}(x)$ for which x is the ex post efficient care level. (Notice that $\hat{\theta}(x) \equiv (x^*)^{-1}(\theta)$.) Under hindsight, for every x the manufacturer is liable if and only if θ falls within the interval $(\hat{\theta}(x), 1]$. Thus the manufacturer chooses x that minimizes

$$x + \int_{\hat{\theta}(x)}^{1} H(x, \theta)\, dF(\theta). \tag{3}$$

Denote by $\hat{x}$ the solution to Equation (3). $\hat{x}$ may be greater or smaller than, but will generally not equal x^*. Hindsight distorts incentives for care because it presents the uninformed manufacturer with the wrong choice. As Edlin (1994) articulated it,[12] the manufacturer is driven by two "incentives." His "incentive #1" is to reduce the range of θ for which he may be found liable. This is a private benefit that has no social value and its effect is to induce excessive care. The manufacturer's "incentive #2" is to reduce the cost of harm, but only for values of θ in the liability range $(\hat{\theta}(x), 1]$. That is, the private concern for harm

11. The analysis in Section 4 would clarify how the choice of liability regime may affect one factor of the production level: the development of new technologies.

12. Similar analysis is presented in Ben-Shahar (1995).

reduction is lesser than the social concern, which could lead to too *little* care. Thus hindsight may induce too much or too little care.[13]

3.4 Legal Implications

The law and economics analysis of the incentives to install safety measures offers two insights which the traditional products liability scholarship neglected to recognize. First, it suggests that the common belief that hindsight leads to greater levels of safety is not necessarily valid. Hindsight may, in fact, lead to lower investment in safety relative to the state-of-the-art defense. This misconception is presumably related to the common view, also inaccurate, that evidentiary uncertainty necessarily leads to overprecaution (e.g., Cooter and Ulen, 1986:1090; Shapo, 1987:9.3). Thus recommendations to adopt a hindsight approach in order to increase product safety should be treated cautiously. Second and more importantly, even if Hindsight leads to greater investment in safety, from a welfare perspective this is an undesirable outcome. A properly administered state-of-the-art rule would lead to more efficient care levels.[14]

The results in this section might be regarded as supportive of the controversial approach taken by the Restatement (Third) of Products Liability. According to § 2(b), a manufacturer should be liable for defective design only if the foreseeable risks it creates could have been reduced by added care or alternative design. The remaining sections will explore and qualify this conclusion.

4. Investment in Advancing Technology

4.1 Doctrinal Background

The analysis above examined the incentives of a manufacturer to install safety devices in the product, given the distribution of risks associated with the known technology. A manufacturer may also invest in making the technology itself

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13. Note that the distortion does not necessarily owe to the formulation of the negligence rule as a discontinuous cost function. One can think of alternative formulations, as in Kahan (1989), in which the magnitude of liability is restricted to cover only the fraction of harm that is due to the manufacturer's negligence. That is, a court that finds negligence may stipulate a compensation that is equal, not to the full harm $H(x, \theta)$, but only to the fraction of harm that would not have occurred had the manufacturer taken due care—that is, a compensation of $H(x, \theta) - H(x^*(\theta), \theta)$. If such a causation doctrine is applied, the same type of distortion would arise, as the manufacturer is still unable to anticipate and choose $x^*(\theta)$. The only difference from the analysis above is that the manufacturer's incentive to set too high a level of x will be weakened. The manufacturer will choose x to minimize

$$x + \int_{\hat{\theta}(x)}^{1} [H(x, \theta) - H(x^*(\theta), \theta)]\, dF(\theta),$$

which compared to the solution of Equation (3), would yield a lower level of x.

14. As explained in Section 3.1, the increased cost that hindsight imposes on manufacturers has the additional implication that manufacturers may choose not to market some products which they would have marketed under the state-of-the-art regime. In light of the a priori bias that negligence regimes create toward excessive levels of activity, this restraining effect of the hindsight rule can only be socially desirable. That is, more efficient product choices will be induced by the hindsight rule, but the safety investment in the chosen products will be generally inefficient.

less dangerous—that is, in shifting the distribution of risks to a less costly one. For example, a producer of electric toasters can change the technology of the heating component so as to make fire accidents less likely; a drug manufacturer can change the active agents to reduce a drug's risks; a producer of an artificial sweetener can develop ingredients that reduce cancer risks.

Like the investments examined in Section 3, these investments reduce the expected harm. They are examined separately, however, for two reasons. First, analytically, legal scrutiny of technological investment differs from legal scrutiny of care levels since the former investment cannot be tailored ad hoc to any particular random harm. Thus the dilemma between choosing ex post versus ex ante standards does not arise.[15] Second, the two types of investments are examined separately in accordance with the institutional capabilities of courts. Doctrinally, investments in technology are usually not part of the standard of due care. Courts are limited in their ability to determine accurately whether a manufacturer was negligent in the decision to promote a particular technology or to engage in a new direction of product development, and therefore they are often reluctant to examine the R&D decision. As stated by the Restatement (Third) of Products Liability, for courts to evaluate the technology choice, victims must show a practicable safer alternative design, prove what injuries would have resulted from the allegedly safer technology (even when it was not in fact utilized), and show that the manufacturer did not observe established research standards.[16] These are formidable tasks. Unless a new technology has become widely known, as well as the costs of developing it, judges and juries may likely err in assessing the desirability of the investment. Regulatory agencies are often in a superior position to collect and process the information required to effectively scrutinize the products' underlying technologies (see Henderson, 1973, 1983). Apparently, even in cases of manifestly flawed technology, like the asbestos or the defective drug cases, courts did not examine the reasonableness of the product's design—whether substitutes should have been developed—only the failure to warn or properly react to mounting knowledge. Hence this section examines the subset of manufacturers' investments that can potentially reduce the cost of harm to society but that, for practical reasons, are not scrutinized directly by legal standards.

The Restatement (Second) of Torts holds the view that hindsight will repress the development of new, experimental technologies. Comment *k* to § 402A

15. One may, of course, write a model in which properties of the distributions of θ are random, gradually revealed over time, thereby subjecting the choice of technology to the same dilemma as the choice of care, that is, the dilemma of choosing between random ex post versus nonrandom ex ante standards. While such a model would eliminate the need for the distinction between the two types of investments, it would not capture the important feature that, at some level of abstraction, the manufacturer knows a distribution of risks—whether it is the distribution of θ, the distribution of distributions of θ, etc., but does not know the actual θ.

16. See Restatement (Third) of Torts: Products Liability § 2(b) and Comment *c* (Proposed Final Draft (Preliminary Version) 1996). These requirements can be found in case law, e.g., *Wilson v. Piper Aircraft*, 579 P.2d 1287 (Or. 1978); *Jeng v. Witters*, 452 F. Supp. 1349 (MD Pa. 1978); and *Owens v. Allis-Chalmers Corp.*, 268 N.W.2d 291 (Mich. 1978).

recognizes that there are unavoidably unsafe technologies, and that liability for design defects may stifle incentives to develop socially valuable technologies. Courts ordinarily share this conjecture. Some courts have speculated that if improvements in technology can, in hindsight, serve as a basis of liability, "the commensurate effect is to discourage improvements in technology."[17] Similarly, it was asserted that a state-of-the-art defense would "remove a disincentive to the development of new drugs that have the potential of conquering disease."[18] The analysis below examines whether or not the state-of-the-art regime would indeed lead to a more desirable pace of technological advancement.

4.2 Extension of the Model

It is assumed that the manufacturer can invest a discrete amount, c, in additional design research. While c is assumed to be discrete, the results will be presented in a way that allows any value of $c \geq 0$ to be considered, thus there will be no loss of generality relative to the continuous case.[19] An investment of c would shift the distribution of θ from the initial riskier $F(\theta)$ to the less risky $G(\theta)$. The measure of riskiness is first-order stochastic dominance. The distribution $G(.)$ is first-order stochastically dominated by $F(.)$, if for every given level of θ, the probability of the product causing a hazard greater than θ is higher under $F(.)$ than under $G(.)$. That is, $G(\theta) \geq F(\theta)$ for all θ. The implication of $G(.)$ being first-order stochastically dominated by $F(.)$ is that it involves a smaller expected harm:[20]

$$\int_0^1 H(x,\theta)\, dF(\theta) \geq \int_0^1 H(x,\theta)\, dG(\theta). \tag{4}$$

Intuitively, the manufacturer can, by investing in technological improvements, shift the distribution of possible dangers to make the lesser harms more likely and the greater harms less likely. Courts are assumed to know θ and its distribution, whether it is $F(\theta)$ or $G(\theta)$. Initially it is assumed that courts

17. *Michael Gregory v. Cincinnati Inc.*, 538 N.W.2d 325 (Mich. 1995). A similar view was voiced by Wade (1983:755).

18. *Toner v. Lederle Laboratories*, 732 P.2d 297 (Id. 1987). In a related line of cases, courts have applied the state-of-the-art defense implicitly, by refusing to admit evidence on the existence of safer technologies if they were developed after the marketing of the harmful product. These courts reasoned that admitting evidence of advances in knowledge would deter manufacturers from developing new, safer, technologies. See, e.g., *Patton v. Hutchinson*, 861 P.2d 1299 (Kan. 1993); *Olsen v. Ohmeda Inc.*, 863 F.Supp. 870 (Wis. 1994); West's Ann. Evid. Code, § 1151. But see *Ault v. International Harvester Co.*, 528 P.2d 1148 (Cal. 1975) for an opposite view.

19. This modeling approach—a discrete choice in the background of continuous care levels—follows Kaplow and Shavell (1996). While it does not limit the generality of the type of claims made in this article, it enables to present results of the form: "there will be technologies that are socially desirable (undesirable) which will not (will) be developed." Given that the development of technologies is often, in practice, a yes/no decision (should ingredient X be introduced in a drug; should anticollision device Y be installed in a car), using a continuous decision variable with respect to choice of technology may obscure the nature of the results.

20. Equation (4) holds for any harm function increasing in θ (i.e., $H_\theta > 0$). For a technical presentation of equivalent formulations of risk dominance, see Hirshleifer and Riley (1992:105–7).

can scrutinize only the level of care x and cannot verify whether or not c was invested or what may have been the distribution shift associated with such an investment.[21] The motivation for this assumption, as explained above, is to examine the indirect effect of legal scrutiny over one variable (x) on the choice manufacturers make with respect to the less readily observed variable (c). Subsequently the possibility that courts can verify x perfectly and c with error will be discussed.

4.3 Incentives to Invest in Technology Under the State-of-the-Art Regime

If the manufacturer does not spend c and the distribution of risks remains at $F(\theta)$, he expects to face a standard of x_F^* and will invest x_F^* in safety.[22] If, however, the manufacturer elects to spend c, the distribution changes to $G(\theta)$ and he will face a more lenient standard of negligence, x_G^*, which is the level of x that minimizes

$$x + \int_0^1 H(x, \theta)\, dG(\theta). \tag{5}$$

The manufacturer will satisfy this standard. Thus, the manufacturer will spend c if and only if $c + x_G^* \leq x_F^*$, or, equivalently, if and only if $c \leq c_{SOA}^P$, where c_{SOA}^P is the privately critical cost under the state-of-the-art regime, and is defined by

$$c_{SOA}^P \equiv x_F^* - x_G^*. \tag{6}$$

From a social point of view, the investment in c is desirable if and only if

$$c + x_G^* + \int_0^1 H(x_G^*, \theta)\, dG(\theta) \leq x_F^* + \int_0^1 H(x_F^*, \theta)\, dF(\theta).$$

That is, the ex ante efficient cost of accidents after the technological improvement plus the cost of investment c must be less than the ex ante efficient cost of accidents prior to the technology improvement. Equivalently the investment in c is socially desirable if and only if $c \leq c_{SOA}^S$, where c_{SOA}^S—the socially critical level of investment—is defined by

$$c_{SOA}^S \equiv \left[x_F^* + \int_0^1 H(x_F^*, \theta)\, dF(\theta)\right] - \left[x_G^* + \int_0^1 H(x_G^*, \theta)\, dG(\theta)\right]. \tag{7}$$

Comparing the private incentive to invest in c with its social desirability, we can establish the following proposition (a proof is given in the Appendix):

Proposition 1. Under the state-of-the-art regime, the manufacturer's investment in developing technologies with lower distribution of risks may be less than, greater than, or equal to the socially optimal investment.

21. See *Gregory v. Cincinnati Inc.*, 538 N.W.2d 325 (Mich. 1995) for an example of the court's reluctance to examine the reasonableness of the choice of product.

22. Subscripts denote the distribution of θ from which the level of x is derived. x_F^* is, accordingly, the ex ante efficient level of x under the distribution $F(\theta)$.

Remark. The reason for the manufacturer's distorted incentives to spend on technology is the existence of an externality. By investing in c and shifting the distribution of θ, the manufacturer generates two social effects: the change in the expected harm given the actual level of x he chooses, and the reduction in the ex ante efficient investment in care, x^*. But the manufacturer, who expects to satisfy the efficient standard of safety x^* and thus escape liability, takes into account only the second benefit, the benefit of a less costly investment in safety (he will be faced with the more lenient standard x_G^*, rather than x_F^*). Since the manufacturer does not take into account the other effect arising from his action—the change in the expected harm—his incentives may be distorted. Further, as the technology becomes safer, the expected harm may not necessarily diminish. The expected harm may at times increase, since the manufacturer is driven to take less care.

4.4 Incentives to Invest in Technology Under the Hindsight Regime

If the manufacturer does not spend c and the distribution of risks remains at $F(\theta)$, he expects to face a random standard of $x^*(\theta)$ and will invest the distorted level $\hat{x}_F$ in care. In this case, the manufacturer will bear liability whenever $\theta > \hat{\theta}(\hat{x}_F)$. If, instead, the manufacturer spends c and the distribution changes to $G(\theta)$, he will invest $\hat{x}_G$ in care and bear liability whenever $\theta > \hat{\theta}(\hat{x}_G)$. Thus the manufacturer will spend c if and only if $c \le c_{HS}^P$, where c_{HS}^P—the private critical cost under the hindsight regime—is

$$c_{HS}^P \equiv \left[\hat{x}_F + \int_{\hat{\theta}(\hat{x}_F)}^1 H(\hat{x}_F, \theta)\, dF(\theta)\right] - \left[\hat{x}_G + \int_{\hat{\theta}(\hat{x}_G)}^1 H(\hat{x}_G, \theta)\, dG(\theta)\right]. \quad (8)$$

From a social point of view, the investment in c is desirable if and only if, given the subsequent distortion in x, the social cost of accidents after the technological improvement plus the cost of investment c is less than the social cost of accidents prior to the technological improvement. Equivalently the investment in c is socially desirable if and only if $c \le c_{HS}^S$, where c_{HS}^S—the socially critical level of investment under the hindsight regime—is defined by

$$c_{HS}^S \equiv \left[\hat{x}_F + \int_0^1 H(\hat{x}_F, \theta)\, dF(\theta)\right] - \left[\hat{x}_G + \int_0^1 H(\hat{x}_G, \theta)\, dG(\theta)\right]. \quad (9)$$

We can establish the following proposition (proved in the Appendix):

Proposition 2. Under the hindsight regime, the manufacturer's investment in developing technologies with lower distribution of risks may be (i) less than, greater than, or equal to the socially optimal investment; and (ii) less than, greater than, or equal to his investment under the state-of-the-art regime.

Remarks. (i) The result in part (i)—the social distortion—arises from the fact that the private gain is the reduction in expected liability, whereas the social gain is the reduction in expected harm. When the manufacturer changes his level of care, it is impossible to determine unambiguously whether the resulting reduction in expected liability is greater than or less than the reduction in expected harm. (The example in the proof provides insight as to how either distortion might arise.) Under which regime the manufacturer invests more in technology depends on the comparison between c^{P}_{HS} and c^{P}_{SOA}. The comparison is again ambiguous: the reduction in the cost of care under the state-of-the-art regime may be greater or smaller than the reduction in the cost of care and liability under the hindsight regime. Hence, either regime might lead to more investment in technology.

(ii) It was assumed that courts do not even attempt to scrutinize the investment in c. Instead, it might be that courts attempt to observe c, but given their institutional limitations, can only do so with (zero mean) error. What happens if courts impose liability on firms whenever x or their observation of c appear to be suboptimal? The results might change in the following way. Being uncertain as to which level of R&D investment would meet the court's standard might lead the firm to engage in a distorted level of investment, as Craswell and Calfee (1986) observed. Under hindsight, however, the firm already expects to bear liability with a positive probability (on account of its choice of x), thus its incentives in investing c will be affected less by the added uncertainty. Under the state-of-the-art rule, since the firm sets x to preclude liability altogether, the added uncertainty will increase its incentive to invest in c. Thus, imperfect legal scrutiny of the R&D investment will have a stronger effect of inducing greater (yet potentially excessive) investment under the state-of-the-art rule.

4.5 Legal Implications

This model does not confirm the conjecture, voiced by some commentators and courts, that a hindsight regime will necessarily slow down the pace of investment in technology advancement. Under both the hindsight and the state-of-the-art regimes, manufacturers bear private costs which they may seek to reduce by promoting technologies. Under the state-of-the-art regime the private costs equal the cost of care (in equilibrium, there is no liability), and under the hindsight regime the private costs include the cost of care and the expected cost of liability. Under the hindsight regime, the new technology will impose greater costs of liability, which is apparently the reason that hindsight is believed to slow down technology advancement. But what is often overlooked is that hindsight also imposes even larger costs under the current technology. Thus hindsight may enhance—not weaken—the incentives to develop a better technology. The fact that under either liability regime we cannot expect to induce optimal rates of technological progress is not surprising. The analysis assumes that legal standards are set with respect to one behavioral variable, x, when full optimization would require control of both variables, x and c. This is an illustration of Shavell's (1987:9) general observation that, for a negligence standard to achieve first-best results, it must be applied to all the relevant variables. While the Restatement (Third) of Products Liability allows, in principle, a judicial scrutiny of both x and c, the "mechanics" of this scrutiny—that a lay jury will examine the scientific and economic features of alternative designs and of R&D choices to determine their optimality—make it often impractical (see Henderson, 1973).

A class of technologies for which hindsight is likely to speed up progress are those that create a small probability for exceedingly high harm, an event that cannot be avoided by ordinary care of manufacturers. Some pharmaceutical products belong to this category—drugs that may, with a slight probability, cause severe side effects that cannot be avoided by added precaution. Here, a shift toward a safer technology that eliminates the chance for such freak harms will more likely be induced by the hindsight regime. Under the hindsight rule, such investment will yield a benefit of lower expected liability, whereas under the state-of-the-art rule there will be smaller incentive to invest in the safer technology, as it might not reduce the cost of conventional care.[23]

5. Incentives to Improve Safety After Distributing the Product

5.1 Background

Until now it was assumed that manufacturers could take various actions prior to the distribution of the product in order to make it safer. Yet manufacturers can also invest in safety after the product has already been released on the market. For example, car manufacturers can collect information regarding the actual safety performance of components and undertake costly recalls to repair them. Or a manufacturer of an electric appliance, who continuously invests in developing new models, can refit old models already on the market by distributing replacement components. This section examines the incentives of manufacturers to undertake such ex post investments under the two liability regimes.

Two intuitive but opposite conjectures have been voiced in the law and economics literature. Many authors have argued that hindsight would provide a disincentive for the manufacturer to discover safety improvements for a product that has already been marketed. In fact, it was suggested that the manufacturer may seek to hide rather than develop available accident-reducing measures. The underlying notion is that by revealing new safety measures, the manufacturer becomes vulnerable to liability in those cases for which the added safety measures did not arrive in time.[24] The opposite view (A. Schwartz, 1985:704) suggests that under hindsight, a firm who has already marketed its product will have a greater incentive to discover the hazards and issue recalls and warnings in order to reduce the frequency of harm.[25] In contrast, with the state-of-the-art defense the firm can avoid liability without any added investment. The analysis below will examine which of these conflicting intuitions is valid.

5.2 Extension of the Model

Suppose that after investing x in the safety of the product, distributing the product and observing the actual realization of θ, but before harm occurs, the man-

23. This argument is illustrated in the shift from $f(\theta)$ to $g^3(\theta)$ in the numerical example within the proof of Proposition 2 in the Appendix.

24. See Henderson (1983), Calabresi and Klevorick (1985:624), and G. Schwartz (1974:484). Shapo (1987:25-11) demonstrates the prevalence of this view among courts.

25. See also *Ault v. International Harvester*, 528 P.2d 1148, 1152 (Cal. 1975).

ufacturer can take risk-specific measures to reduce the expected harm. That is, some risks might become privately known to the manufacturer before they have fully materialized, and added measures to reduce these risks prospectively—measures that were not available originally when θ was unknown—might be taken. Let y denote the manufacturer's cost of such postmarketing care measures, so that the expected harm is $H(x, y, \theta)$, with $H_y < 0$, $H_{yy} > 0$, $H_{yx} > 0$, $H_{y\theta} < 0$ (i.e., diminishing marginal returns to postmarketing care; x and y are substitutes). Assume that y is picked after the manufacturer perfectly observes θ,[26] thus its optimal level minimizes $y + H(x, y, \theta)$. Denote by $y^*(x, \theta)$ this optimal level of y, which—assuming an interior solution—can be derived from the first-order condition $H_y(x, y^*(x, \theta), \theta) = -1$. This condition, along with the assumption that $H_{xy} > 0$, implies $\partial y^*(x, \theta)/\partial x < 0$—that is, the optimal postmarketing care declines with the level of premarketing safety care.

An efficient outcome is characterized by two elements:

(i) Ex post efficient y—given x and θ, y should be set at the optimal level $y^*(x, \theta)$;

(ii) Ex ante efficient x—given its effect on y^* and H, x^* is the level of x that minimizes:

$$x + \int_0^1 [y^*(x, \theta) + H(x, y^*(x, \theta), \theta)]\, dF(\theta). \tag{10}$$

Initially it will be assumed that y can be scrutinized by courts, so that a dual standard system $(\bar{x}, \bar{y})$ can be applied. Subsequently the more interesting case, in which y cannot be scrutinized directly, will be examined. We will then see how liability regimes that are applied only with respect to x might affect the investment in y.

5.3 Investment Under a Dual Standard System

Consider a negligence regime which sets standards of care with respect to both the pre- and postmarketing levels of care. The manufacturer will be held liable unless he meets the standards of care $\bar{x}$ and $\bar{y}$. For example, $\bar{y}$ can be thought of as the postsale duty to warn.[27] The following proposition is proved in the Appendix:

Proposition 3. Suppose courts set the optimal postmarketing standard $y^*(x^*, \theta)$. (i) If, in addition, courts apply the state-of-the-art defense with respect to x (set a standard of x^*), the manufacturer will take the efficient levels x^*, $y^*(x^*, \theta)$; (ii) if, instead, courts apply the hindsight regime with respect

26. This assumption is made for simplification. Similar results would hold whenever the firm acquires any indication as to θ's draw. But notice that if y were to be picked prior to the manufacturer's observation of θ, its level could not have been made contingent on θ, in which case it would have been regarded as an element of the vector x.

27. Restatement (Third) of Products Liability, § 18. See, e.g., *Romero v. International Harvester Co.*, 979 F.2d 1444 (Tenth Cir. 1992).

to x (set a standard of $x^*(\theta)$), the manufacturer will take $\hat{x}$, $y^*(x^*, \theta)$, a less efficient outcome.

Remarks. (i) Intuition. When a dual standard system is operable, the result stated by Proposition 3 is similar to the ideas discussed in Section 3. That is, the ability to set ex post efficient standards, $y^*(x^*, \theta)$ guarantees an efficient outcome with respect to y, and the only remaining issue is the incentive for ex ante safety. In this respect, the distortion hindsight produces with respect to x remains. Put differently, the ability to set ex post standards eliminates the conjectured advantage of the hindsight regime (that it induces better postmarketing safety actions), and what remains is the effect on ex ante care, whereby the state-of-the-art regime is superior.

(ii) This result is another illustration of the general observation that when the controlled behavior has several dimensions ($x, y, z, \ldots$), a system that sets optimal standards for each dimension ($\bar{x}, \bar{y}, \bar{z}, \ldots$) can lead to optimal behavior (Shavell, 1987:9).

(iii) A Note on the Law. In some cases, courts have applied the state-of-the-art defense with respect to premarketing care, while at the same time utilizing all information available ex post to determine the postmarketing duty to warn.[28] This is a desirable dual standard approach. However, as will be explained below, this approach may not be feasible.

5.4 Investment Under a Single Standard System

Consider now a liability system that sets standards only with respect to the premarketing level of safety. This may be the situation when courts are unable to deduce what should be the appropriate standard $\bar{y}$, because of, say, insufficient data regarding the manufacturer's knowledge of the defect, the cost of repair, the accessibility of the distributed products, and the like. That is, it is assumed that courts can identify accurately the premarketing state of the art, x^*, but not the postmarketing efficient standard, due to imperfect information regarding the options the firm might have had at the interim stage in which y is to be taken. In fact, this assumption might explain two prevalent legal practices, the first which establishes that a manufacturer is under no duty to modify its product's safety features (§ 18 of the Restatement (Third) of Products Liability), and the second which disallows evidence about remedial measures a manufacturer has taken after receiving news of accidents.[29] These doctrines imply that, generally, courts only scrutinize the choice of x, not of y.[30]

28. See, e.g., *Seeley v. Cincinnati Shaper*, 606 A.2d 378 (N.J. 1992).

29. For the first rule, see, e.g., *Gregory v. Cincinnati, Inc.*, 509 N.W.2d 809 (Mich. 1993). For the second rule, see the landmark case of *Columbia and Puget Sound R.R. v. Hawthorne*, 144 U.S. 202 (1892) and Rule 407 of the Federal Rules of Evidence for its subsequent codification. See also Judge Posner's opinion in *Flaminio v. Honda Motor Co.*, 733 F.2d 463, 469 (7th Cir. 1984).

30. Courts' imperfect information about y may be due to firms' efforts to conceal these investments. See, e.g., the claim that an automaker withheld information about repairable fire hazards (*New York Times*, May 12, 1998:C2). If firms can indeed conceal information about care investments, they may likewise overstate the actual level of x. It should be noted, however, that the

What effect would the two liability regimes, when applied only with respect to the choice of x, have on the manufacturer's combined investment in care? Notice that under both the state-of-the-art and the hindsight regimes, the manufacturer would have an incentive to invest positive levels of y if and only if, after setting x, he still expects to bear liability. For if he satisfies the standard $\bar{x}$, no liability is anticipated and there is no return to investment in y, in which case its level will be set at zero. (Of course, a manufacturer may invest in new safety measures even if he does not expect liability for the marketed product, whenever this investment improves future models of the product. However, even if he makes such investments, he will not adapt them to previously marketed products since the liability rule does not require him to do so and because he might fear that, by exposing the risks that the new measures address, he "invites" lawsuits.)

Proposition 4. Under the state-of-the-art regime, the manufacturer will invest x^* in premarketing safety and $y = 0$ in postmarketing safety.

Proposition 5. Under the hindsight regime, (i) the manufacturer's investment in postmarketing safety is less than the socially optimal level, given his investment in premarketing safety; (ii) the manufacturer's investment in premarketing safety may be less than, greater than, or equal to the socially optimal level.

Proofs. See Appendix.

Remarks. (i) Superior Postmarketing Safety Investment Under the Hindsight Regime. The level of postmarketing investment under the hindsight regime is greater, and more efficient, than the level under the state-of-the-art regime. The ex ante distortion that hindsight creates leads to a smaller ex post distortion. Put differently, the hindsight regime incorporates "pockets" of strict liability, which lead to better decisions regarding postmarketing safety than the state-of-the-art regime which has no such pockets and creates no incentives to invest in postmarketing safety.[31]

(ii) Superior Premarketing Investment Under the State-of-the-Art Regime. The level of premarketing care under the state-of-the-art regime is either greater or smaller, but is more efficient, than the level under the hindsight regime. The ex ante optimal x is taken under the state-of-the-art rule,[32] whereas a distortion identical to the one identified in Section 3 affects the investment under the hindsight regime. Put differently, the mere addition of ex post opportunity to

incentive to conceal information about y would arise only under the hindsight regime, with the intention to bias the judicial estimate of θ; it would not arise under the state-of-the-art rule, as the standard of care is independent of y or θ. However, the incentive to overstate x would arise under both regimes and should not, per se, affect the comparison among them.

31. For a similar claim, founded on the same intuition, see A. Schwartz (1985).

32. The proof to Proposition 4 confirms that under the state-of-the-art rule, it will never be in the firm's interest to take less than due care initially, await the realization of θ, and subsequently take either zero or high postmarketing care.

reduce harm does not change the qualitative ranking of the two regimes with respect to ex ante care, only their overall rating.

(iii) Overall Comparison. Since the hindsight regime is superior with respect to y and inferior with respect to x, the overall comparison is ambiguous. Roughly, the desirability of hindsight increases as the relative importance of postmarketing safety rises. This implies that the liability rule should optimally be industry specific. For example, in situations in which there is a significant time interval between the point at which manufacturers observe θ (the first reliable signs of harm) and the point at which harm occurs, it will be more desirable to adopt the hindsight regime and emphasize the incentives to take postmarketing measures. Such may often be the case in the automobile industry. In contrast, when the manufacturer has little or no practical opportunity to refit a product that is already sold, the state-of-the-art regime would be desirable. This may likely be the case in the pharmaceutical and medical implants industries. Also, when the tasks a product performs vary widely across consumers, as in the case of many types of industrial machines, accidents may be user specific and full-scale repairs may not be desirable. In such cases the state-of-the-art rule would be superior.

6. Incentives to Become Informed Ex Ante

6.1 Background

It was established that if the manufacturer does not have full knowledge of the dangers associated with the normal use of his product, applying this knowledge ex post to determine his liability will have adverse effects on the care levels. However, this result stands only inasmuch as the manufacturer will choose to remain uninformed about the dangers when designing the product. The manufacturer can instead become better informed by investing more in tests and research of the product's usage dangers prior to its distribution. That is, every unknown danger is "knowable"—there is always a level of investment in information that can identify it, ex ante.

In a substantial line of cases, courts have speculated that the hindsight regime will have the advantage of inducing manufacturers to become informed ex ante. In light of the fact that manufacturers are in the best position to judge whether avoidance costs are justified, courts considered the information acquisition effect of hindsight desirable.[33] Courts did not examine, however, whether the manufacturers' investment in information could be excessive. This is one question that will be addressed in the analysis below.

Shavell (1992) has demonstrated that a negligence rule based on the ex post efficient level of care (a hindsight rule) may lead parties to obtain information about risk when doing so is too costly.[34] As Shavell explains it, a party's private benefit from learning the precise risk and choosing optimal care is the escape

33. See, e.g., *Beshada v. Johns-Manville Corp.*, 447 A.2d 539, 548 (N.J. 1982).

34. Other articles that have looked at the information acquisition effects of the negligence liability rule include Calabresi and Klevorick (1985:621–3), A. Schwartz (1985), and Kaplow and Shavell (1992).

from liability. The social benefit from information acquisition is smaller, since choosing optimal care does not eliminate harm, only reduces it. The analysis below examines the implications of this effect with respect to the comparison between the two liability regimes.

6.2 Extension of the Model

Formally, suppose that at time 0 the manufacturer can engage in additional testing of the product's risks. It is assumed that if the manufacturer will spend a discrete cost of k he will be able to anticipate θ perfectly, and thus be able to anticipate $x^*(\theta)$, the ex post efficient standard. That is, it is assumed that at time 0 the manufacturer faces a binary problem: either spend k and know θ or spend zero and know only $F(\theta)$.[35]

Throughout it is assumed that the firm's investment in k is nonverifiable in courts. If courts were to know whether or not the firm invested k, the legal scrutiny of this investment could follow, for example, A. Schwartz's (1985) recommendation to utilize negligence standards in scrutinizing the investment in k, and, in the general spirit of a "dual standard" system, produce optimal information acquisition decisions. Nonverifiability is a plausible assumption in this context since unlike x, k is often invested secretly in a way that can be easily hidden from courts.[36] Put differently, courts are assumed to be able to reconstruct ex post the received scientific state of the art—the knowledge that the R&D community openly shared—but cannot reconstruct the actual knowledge of any specific firm. Further, while courts know θ, they cannot necessarily infer how costly it would have been for the firm to anticipate θ (and thus whether it should have spent k). The knowledge of courts is gained by the experience of the product, whereas the alleged knowledge of the firm could have only been gained by pioneering and confidential R&D effort. Thus, if a manufacturer had secretly spent k and acquired an informational edge relative to the contemporary scientific community, this fact would ordinarily remain obscure, both for liability reasons and other, competition-related reasons. When the actual information that the firm had cannot be accurately verified in courts, the remaining alternative is to attribute to manufacturers the knowledge of the state of the art. This is the motivation for the analysis below, which inquires how negligence standards that are applied with respect to the verifiable actions of the firm affect the firm's incentives to become informed.

35. This depiction does not limit the generality of the results relative to a continuous-k framework, since we can examine the effects of changing magnitudes of k. Using a discrete variable to model the information acquisition decision follows previous treatments of this identical issue to which the results will be compared, most notably the models in Shavell (1992) and in Kaplow and Shavell (1992).

36. For example, recent rumors about the tobacco industry's knowledge of smoking hazards indicate how difficult it would be for society to verify and scrutinize the investment in information directly.

6.3 Incentives to Become Informed Under the State-of-the-Art Regime

At first glance, it may seem that if the court ignores the actual value of θ, the manufacturer will never have any incentive to spend k and discover θ ex ante. The manufacturer can escape liability, even when ignorant of θ, by setting x^*. However, this impression may not be valid. The manufacturer may have an incentive to acquire information about θ in anticipation that, if θ turns out to be lower than what is conceived to be the "average" risk (lower than $\hat{\theta}(x^*)$), he will present it ex post to the court as the known (and lenient) state of the art, thus enjoying a lower standard of due care than would otherwise be applied ($x^*(\theta) \leq x^*$). Of course, if the manufacturer's inquiry reveals a high level of $\theta(\theta > \hat{\theta}(x^*))$, he could suppress this information and enjoy, under the state-of-the-art defense, the moderate standard based on $F(\theta)$. He will spend k if and only if

$$k + \int_0^{\hat{\theta}(x^*)} x^*(\theta)\, dF(\theta) + [1 - F(\hat{\theta}(x^*))]x^* \leq x^*. \tag{11}$$

The left-hand side of Equation (11) is the cost when acquiring information, which equals k plus the expected cost of the ex post efficient level of care when θ turns out to be low, plus the cost of the ex ante efficient level of care when θ turns out to be high. This cost has to be lower than the alternative—the cost of the ex ante efficient level of care. Stated differently, the manufacturer will spend k if and only if $k \leq k^{\mathrm{P}}_{\mathrm{SOA}}$, where $k^{\mathrm{P}}_{\mathrm{SOA}}$—the private critical cost under the state-of-the-art regime—equals

$$k^{\mathrm{P}}_{\mathrm{SOA}} \equiv \int_0^{\hat{\theta}(x^*)} (x^* - x^*(\theta))\, dF(\theta). \tag{12}$$

Notice, however, that the manufacturer's private gain from information—the right-hand side of Equation (12)—exceeds the social gain. Precisely, the private gain is greater by

$$\int_0^{\hat{\theta}(x^*)} [H(x^*(\theta), \theta) - H(x^*, \theta)]\, dF(\theta).$$

That is, whenever the manufacturer adjusts his care downwards (from x^* to $x^*(\theta)$, there is an increase in the social cost of harm (from $H(x^*, \theta)$ to $H(x^*(\theta), \theta)$). This negative externality implies that the manufacturer has excessive incentive to spend k. The general argument that negligence regimes lead to excessive investment in information (Shavell, 1992) applies for similar reasons under the state-of-the-art negligence rule.[37] We can thus state:

37. The one-sided distortion derived in this analysis is not due to the fact that k is modeled as a discrete rather than continuous variable. Unlike other variables (e.g., x), for which the discrete framework could potentially obscure the fact that the distortion may go either way (as, say, in Shavell, 1992), here there is in general only one distorting effect—the negative externality.

Proposition 6. When the manufacturer can perfectly anticipate θ by an ex ante research expenditure of k, the state-of-the-art regime may lead the manufacturer to spend k even when it is socially undesirable.

Remark. Observable Investment. The analysis assumes that the manufacturer can hide his knowledge if he learns that θ is high. If this were not the case—that is, if once the manufacturer acquires information about θ he would be held to the corresponding optimal standard—the manufacturer will have a weaker incentive to acquire information about θ. The manufacturer will assign a smaller private value to information, because by acquiring information about θ he may be held to a higher, costlier standard (whenever $\theta > \hat{\theta}(x^*)$).[38] This dilution of the incentives could be a desirable effect, since otherwise the manufacturer spends k too often. That is, under the state-of-the-art regime it may be socially desirable, whenever θ is high, for courts to try to detect whether θ was revealed secretly by the manufacturer ex ante and, if so, adjust the standard upwards to $x^*(\theta)$.

6.4 Incentives to Become Informed Under the Hindsight Regime

Under this regime, the manufacturer can satisfy the random standard $x^*(\theta)$ by spending k and anticipating θ perfectly. In such a case, he will abide by the standard and will never have to bear liability. The manufacturer can also choose to remain ignorant of the actual risk and save the cost of k. Then his best strategy is to invest $\hat{x}$ in safety—the privately optimal investment under the Hindsight regime, given his ignorance. The manufacturer will choose to spend k if and only if

$$k + \int_0^1 x^*(\theta)\, dF(\theta) \le \hat{x} + \int_{\hat{\theta}(\hat{x})}^1 H(\hat{x}, \theta)\, dF(\theta).$$

The left-hand side is the manufacturer's expected cost if he spends k and subsequently takes the ex post optimal level of care; the right-hand side is the manufacturer's expected cost if he remains ignorant and takes $\hat{x}$. Stated differently, the manufacturer will acquire information if and only if $k \le k^{\mathrm{P}}_{\mathrm{HS}}$, where $k^{\mathrm{P}}_{\mathrm{HS}}$—the private critical cost of information under the hindsight regime—is

$$k^{\mathrm{P}}_{\mathrm{HS}} \equiv \hat{x} + \int_{\hat{\theta}(\hat{x})}^1 H(\hat{x}, \theta)\, dF(\theta) - \int_0^1 x^*(\theta)\, dF(\theta). \tag{13}$$

Notice again that the manufacturer's private gain—the right-hand side of Equation (13)—exceeds the social gain from information. Precisely, the private gain

38. If the manufacturer is held to the standard corresponding to any value of θ he reveals, he will acquire information if and only if $k + \int_0^1 x^*(\theta) dF(\theta) \le x^*$, that is, if and only if

$$k \le k^{\mathrm{P}}_{\mathrm{SOA}} + \int_{\hat{\theta}(x^*)}^1 (x^* - x^*(\theta)) dF(\theta).$$

Since the right-hand side is less than $k^{\mathrm{P}}_{\mathrm{SOA}}$, the manufacturer will have a diluted incentive to spend k.

is greater by

$$\int_0^{\hat{\theta}(\hat{x})} [H(x^*(\theta), \theta) - H(\hat{x}, \theta)] \, dF(\theta) + \int_{\hat{\theta}(\hat{x})}^1 H(x^*(\theta), \theta) \, dF(\theta).$$

That is, the manufacturer ignores two social costs: the cost of increased harm in cases in which he has avoided liability (whenever $\theta \leq \hat{\theta}(x^*)$) but is now led to adjust care downward, and the full cost of harm in cases in which he would have borne liability (whenever $\theta > \hat{\theta}(x^*)$) but with the acquired information manages to avoid liability. Thus,

Proposition 7. When the manufacturer can perfectly anticipate θ by an ex ante expenditure of k, the hindsight regime will lead the manufacturer to spend k even when it is socially undesirable.

6.5 Comparison of Regimes

In general, it is impossible to determine unambiguously which regime will give the manufacturer a greater incentive to acquire information. Four cases can potentially arise, each with different legal implications.

Case I: No investment in k is made under either regime ($k > k^P_{HS}$ and $k > k^P_{SOA}$) In this case, since no investment is made in becoming informed, the only dimension in which the regimes differ is their effect on the manufacturer's level of care, x. In this case, we know from Section 3 that the state-of-the-art regime is superior. Thus, for example, in situations in which it is very costly to delay the distribution of a product in order to first reveal its full risks (as in many essential drugs and medical products), the state-of-the-art regime is desirable.[39] In general, products whose harms are revealed only after long periods of consumer usage are essentially the ones for which ex ante knowledge is likely to be too costly to acquire.

Case II: Investment in k is made under both regimes ($k < k^P_{HS}$ and $k < k^P_{SOA}$) In this case, the hindsight regime is unambiguously superior. Since both regimes lead to the expenditure of k and to the efficient level of care when θ is low, their only difference is when θ is high. Then, the hindsight rule still leads to the ex post efficient level of care, whereas the state-of-the-art rule might lead to the inferior, ex ante efficient level of care. The hindsight rule eliminates the manufacturer's incentive to suppress his acquired information whenever θ is high. This superiority is independent of whether or not the acquisition of information itself was socially desirable. Thus if the Hindsight rule applies, it leads to more desirable behavior whenever k is low. The law cannot, however, condition the execution of a hindsight approach on the level of k, so as to restrict it only to low levels of k, since courts are assumed to be unable to verify k and to correctly appreciate whether, ex ante, it was worth investing. For if k were

39. This approach is embodied in Comment k of § 402A of Restatement (Second) of Torts. See V. Schwartz (1985).

verifiable, courts would be able to induce optimal investments in k by setting negligence standards with respect to this decision variable.[40]

Case III: Investment in k is made only under the hindsight regime ($k \leq k^{P}_{HS}$ and $k > k^{P}_{SOA}$) When the manufacturer becomes informed only under the hindsight regime, it is ambiguous which regime is socially desirable. Precisely, the hindsight regime will be superior to the state-of-the-art regime only if, in addition:

$$k + \int_0^1 [x^*(\theta) + H(x^*(\theta), \theta)]\, dF\theta \leq x^* + \int_0^1 H(x^*, \theta)\, dF(\theta). \tag{14}$$

The left-hand side of Equation (14) denotes the social cost under the hindsight regime and the right-hand side denotes the social cost under the state-of-the-art regime. The fact that hindsight leads the manufacturer to be informed does not, we see, guarantee its desirability. Notice that the social value of information under hindsight is not the full cost reduction due to the shift from $\hat{x}$ to $x^*(\theta)$ (as, e.g., is argued by Kaplow and Shavell, 1992). When the manufacturer is uninformed, the best regime is not the hindsight regime that leads him to take $\hat{x}$, but the state-of-the-art regime that implements x^*. Since society can improve from $\hat{x}$ to x^* without any cost of information acquisition, by simply rejecting the hindsight regime, the social value of information is limited to the cost reduction arising only from the incremental shift from x^* to $x^*(\theta)$.

Case IV: Investment in k is made only under the state-of-the-art regime ($k \leq k^{P}_{SOA}$ and $k > k^{P}_{HS}$) In this case, the state-of-the-art regime is superior only if, in addition,

$$k + \int_{\hat{\theta}(x^*)}^1 [x^* + H(x^*, \theta), \theta)]\, dF(\theta) + \int_0^{\hat{\theta}(x^*)} [x^*(\theta) + H(x^*(\theta), \theta)]\, dF(\theta)$$
$$\leq \hat{x} + \int_0^1 H(\hat{x}, \theta)\, dF(\theta).$$

The left-hand side is the social cost under the state-of-the-art regime, given that the information may be suppressed, and the right-hand side is the social cost under the hindsight regime. Hindsight leads to a distortion of x, whereas the state-of-the-art regime imposes a potentially excessive investment in k. Either distortion may be greater.

7. Concluding Remarks

7.1 Summary of Results and Policy Implications

Table 1 summarizes the results of this article. Several implications can be drawn from this table. First, the comparison does not always yield unambiguous

40. This approach can be viewed as arising from §§ 289, 290 of the Restatement (Second) of Torts, which were interpreted to apply a hindsight regime by imposing a duty to acquire information when the cost of doing so is not too high. See, e.g., *Equilease Corp. v. Smith Int. Inc.*, 588 F.2d 919 (1979).

Table 1. Summary of Results

Type of Incentive	Hindsight Rule	State-of-the-Art Rule	Superior Incentive Under
Safety before product distribution	Inefficient. Either too high or too low	Efficient	State-of-the-art rule
Develop new technologies	Inefficient. Either too high or too low	Inefficient. Either too high or too low	Ambiguous
Safety after product distribution	Too low	Too low	Hindsight
Become informed ex ante	Too high	Too high	State of the art if cost of information is high; hindsight if cost is low

results. This reflects a reality in which complex factors blend to motivate the firms, and no single factor dominates. This result is in contrast to the tradition of arguments on the same topic which have often been presented in unconditional and oversimplifying terms. By showing the indeterminacy, and at the same time pointing to the definitive tones prevalent in the legal literature, the first contribution of this article is to caution policy proposers and courts from reaching unbalanced conclusions.

Second, the comparison suggests that the "universality" of products liability law—the fact that its doctrines apply generally across all products—might not be the optimal jurisprudential approach. Since different products might pertain to altogether different sets of social interests, it is desirable to have different laws of products liability for different industries. That is, counter to the fundamental doctrine arising from the common law of products liability and embraced by the new Restatement (Third) of Products Liability, which maintains a unified liability approach to all harms arising from defective design of products, this analysis implies that the liability rule should optimally be industry or category specific. Indeed, there already exists a vocal advocacy in favor of product-category liability (e.g., Page, 1996:106–14). But the existing proposals are founded on the idea that different products involve different social utility (cigarettes or guns as opposed to essential drugs). This article offers a different rationale for product-category liability. In industries in which society is interested in promoting particular safety efforts by the manufacturers, the liability rule should be different than in industries in which this goal is less important or less feasible.

Thus, despite the general indeterminacy of the results, policy recommendations can be drawn. For example, in industries in which it is socially important and at the same time feasible to promote postdistribution safety efforts by manufacturers (as in, say, the automobile and aircraft industries or, often, the children's toys industry), and yet it is difficult to monitor such efforts directly due to lags in the public's knowledge of the defects, a hindsight rule should be preferred. The analysis demonstrated that the hindsight regime will unambiguously advance this goal, even if at the cost of inferior predistribution safety incentives. In contrast, in industries in which society is likely to bear very high costs if manufacturers will be induced to delay product distribution for additional testing until full information about risks is acquired (as in, say, the pharmaceutical industry), a state-of-the-art rule should be preferred. Further, products which can be used in radically different ways by consumers and subjected to different tasks (as are many heavy industrial machines, food products, and perhaps firearms) allocate a more important role to user precautions. In these cases, the state-of-the-art rule would be instrumental in shifting a preventive burden to consumers and leading them to select heterogeneous, privately optimal precautions. Lastly, industries in which scientific advancement is intense and the state of the art changes rapidly (as in parts of the medical devices industry or telecommunications), the prima facie case for the state-of-the-art rule is strengthened. In such industries, there appear to be sufficient incentives for technology advancement from sources other than the liability regime. The rate of introduction of new products provides evidence about the safety of old models, allowing society to scrutinize the postdistribution care levels. The social concern should thus be to provide better incentives to make the products safer prior to distribution.

7.2 Additional Factors

There are additional economic factors that might bear on the comparison between the liability regimes. Below is a list of such factors along with a brief, speculative, discussion of their potential effects. However, as these factors merit a careful exploration, the discussion here should be taken merely as a motivation and an agenda for further research.

Risk spreading. The two regimes can be compared with respect to their risk-spreading qualities. Holding the amount of harm and the state of technological development fixed, and focusing only on manufacturers' and consumers' relative capacities to bear risk, it may be argued that manufacturers are the superior risk-bearers. Although they may not be able to purchase liability insurance for such unanticipated risks, they may be able to self-insure through prices, or may simply have deeper pockets.[41] This factor might seem to operate in favor of the hindsight rule, which inflicts a greater portion of the accidents' costs on firms. However, this form of self-insurance raises the incidence of bankruptcy, and with expensive bankruptcy proceedings it might become a very costly form of insurance.

41. See Keeton (1970); *Beshada v. Johns-Manville*, 447 A.2d 539 (N.J. 1982).

Litigation costs. While the hindsight regime incorporates more knowledge and information into the adjudication process, it may be cheaper to litigate. Courts may find it easier to determine the current state of knowledge than to inquire into the state of the art during the time of design and manufacture, which may have taken place decades before.[42] In addition, cognitive biases—in particular, the "hindsight bias"—may make it difficult for courts to accurately infer $F(\theta)$ and the old state of the art (Rachlinsky, 1998). Thus enriching the analysis by incorporating the differential litigation costs across regimes might blur, or potentially reverse, some of the results derived here.

Market structure. The choice of liability regime may affect the industry concentration. A hindsight rule can generate conflicting effects. On the one hand, with its heavier liability burden, hindsight could create a barrier to entry and also raise the incidence of bankruptcy, thereby increasing concentration. On the other hand, productive operations could potentially be organized among smaller dispersed firms, to put less at stake in the event of massive liability. This raises the danger that firms would be operating at inefficient scales.

Capital structure. The choice of liability regime may also affect the firm's internal capital structure. A hindsight rule increases the riskiness of the firm's operations, which in turn reduces the firm's ability or inclination to issue debt. Firms will thus be more likely to operate under suboptimal capital structures. Further, since tort claimants are general creditors whose priority, under current bankruptcy law, is behind secure lenders, firms will have an incentive to secure debt and to insulate against tort suits. This might lead to socially excessive secured debt financing.

Consumer precaution. Consumers may have different incentives to engage in harm-reducing actions, depending on the manufacturers' liability. If manufacturers are not liable for unanticipated risks, victims will have to bear the costs; thus the incentives operating upon consumers would be more powerful to act cautiously or to become informed of potential risks. For example, operators of industrial machinery (or their employers) would practice greater care in handling new machines when the operation hazards are not yet known. Thus products whose harms can be more easily identified by consumers and relatively efficiently avoided (as would be the case with, say, forklifts, but not with cigarettes or cellular phones), the argument for the State-of-the-Art rule might be reinforced.

7.3 Strict Liability Versus Negligence

The legal literature often identifies the hindsight regime with strict liability and the state-of-the-art regime with negligence (Keeton, 1969). True, hindsight does incorporate "pockets" of strict liability, whereas state of the art is a pure

42. See *Halpen v. Johns-Manville Sales Corp.*, 484 So.2d 110, (La.1986).

negligence regime. However, the hindsight regime creates distorted incentives for the sole reason that it is not a pure strict liability rule, and it "tempts" the manufacturer to exploit the opportunity to escape liability by clearing the negligence hurdle and arriving at the random level of due care. A pure strict liability rule, which makes the manufacturer liable for the random harm regardless of his level of care, outperforms the hindsight regime, and—as Kaplow and Shavell (1996) have demonstrated—leads the manufacturer to take the ex ante efficient level of care and to make the optimal ex ante investment in acquisition of information.

Appendix

Proof of Proposition 1. Comparing Equations (6) and (7) we can see that

$$c^P_{SOA} - c^S_{SOA} = \int_0^1 H(x^*_G, \theta)\, dG(\theta) - \int_0^1 H(x^*_F, \theta)\, dF(\theta). \quad \text{(A1)}$$

The right-hand side of Equation (A1) may be negative, positive, or zero. The first integral may be greater than the second integral because x^*_G is less than x^*_F, or the first integral may be smaller than the second integral because $G(.)$ is first-order stochastically dominated by $F(.)$. The possibility of the sign going either way can be proven with an example. Let $H(x, \theta) = p(x)\theta + x$, where θ is interpreted as the random harm and $p(x)$ is the likelihood of harm. Suppose θ is drawn from $\{100, 200, 300, 400, 500\}$. Further, suppose $p(x)$ is such that $x^*(\theta)$ takes the values and the associated probabilities of harm, as shown in Table 2.

For the proofs of Propositions 1 and 2, we will consider four possible distributions shown in Table 3. All three g distributions are first-order stochastically dominated by f. For $f(\theta)$, average θ equals 300, implying that under the state-of-the-art regime the optimal standard of care is $x^*_F = 50$, thus private costs equal 50 and social costs equal $50 + (.24 \times 300) = 122$. Consider the shift to $g^1(\theta)$. Average θ now equals 200, in which case the optimal standard of care is $x^*_G = 35$, and social costs are $35 + (.3 \times 200) = 95$. Calculating the private and social critical values of investment in shifting technology from f to g^1, we get $c^P_{SOA} = 50 - 35 = 15$ and $c^S_{SOA} = 122 - 95 = 27$. Here is an example for $c^S_{SOA} > c^P_{SOA}$. Consider, alternatively, the shift from f to g^2, with ε very close to 0. Under g^2, average θ equals just under 250, $x^*_G = 35$, and social costs are approximately $35 + (.3 \times 250) = 110$. In this case, $c^P_{SOA} = 50 - 35 = 15$ and $c^S_{SOA} = 122 - 110 = 12$. Here is an example for $c^S_{SOA} < c^P_{SOA}$. Hence the distortion may go either way. ■

Proof of Proposition 2. Comparing Equations (8) and (9) we get

$$c^S_{HS} - c^P_{HS} = \int_0^{\hat\theta(\hat x_F)} H(\hat x_F, \theta)\, dF(\theta)] - \int_0^{\hat\theta(\hat x_G)} H(\hat x_G, \theta)\, dG(\theta)]. \quad \text{(A2)}$$

The two integral terms on the right-hand side of Equation (A2) differ with respect to the upper bound, the distributions, and the level of x. Since we cannot compare the levels of $\hat x_F$ and $\hat x_G$ unambiguously, we cannot determine

Table 2.

θ	100	200	300	400	500
$x^*(\theta)$	20	35	50	60	69
$p(x)$	.4	.3	.24	.21	.19

Table 3.

θ	100	200	300	400	500
$f(\theta)$	.2	.2	.2	.2	.2
$g^1(\theta)$	.4	.3	.2	.1	0
$g^2(\theta)$	.3	.3	.1	.2+ε	.1-ε
$g^3(\theta)$	.2	.2	.2	.4	0

whether the difference between the two integrals is positive or negative. The possibility of the sign going either way can be proved with an example. Consider the example from the proof of Proposition 1. For the distribution $f(\theta)$, the manufacturer takes $\hat{x} = 69$, in which case his private costs are 69 and social costs are $69 + (.19 \times 300) = 126$. For $g^1(\theta)$, we get $\hat{x}_G = 50$, with associated private costs of $50+(.24\times.1\times400) = 59.6$ and social costs of $50+(.24\times200) = 98$. Calculating the private and social critical values of investment in shifting technology from f to g^1 under the hindsight regime, we get $c^P_{HS} = 69-59.6 = 9.4$ and $c^S_{HS} = 126-98 = 28$. Here is an example for $c^S_{HS} > c^P_{HS}$. Alternatively, consider the shift from f to g^3 (which is presented in Table 3). Here, $\hat{x}_G = 60$, private costs = 60, and social costs = $60 + (.21 \times 280) = 118.8$. In this case, $c^P_{HS} = 69 - 60 = 9$ and $c^S_{HS} = 126 - 118.8 = 7.2$. Here is an example for $c^S_{HS} < c^P_{HS}$. Hence the private-social distortion under the hindsight regime can go either way.

For the proof of the second part of the Proposition, again we can show by example that the comparison between c^P_{SOA} and c^P_{HS} can go either way. Combining calculations from the first part of this proof and the proof of Proposition 1, we have a case—the shift from $f(\theta)$ to $g^1(\theta)$—in which $c^P_{SOA} = 15$ and $c^P_{HS} = 9.4$, that is, a case of $c^P_{SOA} > c^P_{HS}$. For the opposite case, consider the shift from f to $g^3(\theta)$. $c^P_{SOA} = 0$ since $x^*_F = x^*_G = 50$, but $c^P_{HS} = 9$, as calculated above. Hence $c^P_{SOA} < c^P_{HS}$, illustrating that the distortion can go either way. ■

Proof of Proposition 3. (i) Under the state-of-the-art defense that sets x^* as the standard of safety with respect to x, if the manufacturer had taken at least x^* ex ante he will be led to take $y^*(x^*, \theta)$ ex post (since he does not need to take more than $y^*(x^*, \theta)$ to escape liability, and if he takes less than $y^*(x^*, \theta)$ he becomes liable for the entire harm which, by definition, is costlier.) If, however, the manufacturer had taken less than x^* ex ante, he will choose $y > y^*(x^*, \theta)$ (since he bears full liability, he will choose y that minimizes it, $y^*(x, \theta)$, and $x < x^*$ implies that $y^*(x, \theta) > y^*(x^*, \theta)$). In this case, his total cost will be

$$x + \int_0^1 [y^*(x, \theta) + H(x, y^*(x, \theta), \theta)]\, dF(\theta).$$

But since, by definition [see Equation (10)], this cost attains its minimum at x^*, it must be that

$$x^* + \int_0^1 y^*(x^*, \theta)\, dF(\theta) < x + \int_0^1 [y^*(x, \theta) + H(x, y^*(x, \theta), \theta)]\, dF(\theta),$$

and the manufacturer is better off taking x^* ex ante.

(ii) Under the hindsight regime, the level of y that the manufacturer will set ex post depends on whether he is liable or not. If, when θ realizes, x turns out to be ex ante negligent, the manufacturer cannot escape liability no matter what level of y he sets and he will take y to minimize $y + H(x, y, \theta)$, that is, $y^*(x, \theta)$. If, instead, when θ realizes, x turns out to satisfy due care, the manufacturer will be liable only if $y < y^*(x^*, \theta)$, and he will choose $y^*(x^*, \theta)$. Expecting to choose either $y^*(x^*, \theta)$ or $y^*(x, \theta)$ ex post, the manufacturer will set the ex ante a level of x that minimizes:

$$x + \int_0^{\hat{\theta}(x)} y^*(x^*, \theta)\, dF(\theta) + \int_{\hat{\theta}(x)}^1 [y^*(x, \theta) + H(x, y^*(x, \theta), \theta)]\, dF(\theta).$$

Differentiating this expression with respect to x and letting $\hat{x}$ denote the solution yields

$$\begin{aligned} &1 + \hat{\theta}'(\hat{x}) f(\theta)[y^*(x^*, \theta) - y^*(\hat{x}, \theta) - H(\hat{x}, y^*(\hat{x}, \theta), \theta)] \\ &+ \int_{\hat{\theta}(\hat{x})}^1 \left[\frac{\partial y^*(x^*, \theta)}{\partial x} + H_x(\hat{x}, y^*(\hat{x}, \theta), \theta) \right. \\ &\qquad \left. + H_y(\hat{x}, y^*(\hat{x}, \theta), \theta) \frac{\partial y^*(\hat{x}, \theta)}{\partial x} \right] dF(\theta) = 0. \end{aligned} \tag{A3}$$

From the first-order condition characterizing x^* [differentiating Equation (10)] we have

$$\begin{aligned} 1 + \int_0^1 &\left[\frac{\partial y^*(x^*, \theta)}{\partial x} (1 + H_y(x^*, y^*(x^*, \theta), \theta)) \right. \\ &\left. + H_x(x^*, y^*(x^*, \theta), \theta) \right] dF(\theta) = 0. \end{aligned} \tag{A4}$$

Suppose $\hat{x} = x^*$. Plugging it into Equation (A3) and comparing the two first-order conditions we get

$$\begin{aligned} -\frac{1}{f(\theta)} \int_0^{\hat{\theta}(x^*)} &\left[\frac{\partial y^*}{\partial x} (1 + H_y(x^*, \theta)) + H_x(x^*, y^*(x^*, \theta), \theta) \right] dF(\theta) \\ &= \hat{\theta}'(x^*) H(x^*, y^*(x^*, \theta), \theta). \end{aligned}$$

The left-hand side depends on $f(\theta)$ and the right-hand side does not. Thus the equality cannot hold for all distributions of θ, and the assumption that $\hat{x} = x^*$ leads to a contradiction. ■

Proof of Proposition 4. If the manufacturer sets x^*, he will not be liable regardless of θ, in which case he will set $y = 0$. His total costs will be x^*. The manufacturer will not set a level $x > x^*$, which only raises his cost of care. He will also not set a level $x < x^*$, because if he does, he will be liable for every θ, he will set $y^*(x, \theta)$, and his total cost will be

$$x + \int_0^1 [y^*(x, \theta) + H(x, y^*(x, \theta), \theta)]\, dF(\theta),$$

which is identical to Equation (10) and, by definition, attains minimum at x^*. ■

Proof of Proposition 5. (i) Under the hindsight regime, the manufacturer is liable if and only if $\theta > \hat{\theta}(\hat{x})$. When $\theta \leq \hat{\theta}(\hat{x})$, the manufacturer is not liable, has no incentives to invest in y, and will set $y = 0$. If, however, $\theta > \hat{\theta}(\hat{x})$, the manufacturer has an incentive to reduce his expected liability by spending y. Knowing θ, the manufacturer will choose y to minimize his expected liability costs, $y + H(\hat{x}, y, \theta)$, and set the ex-post efficient level, $y^*(\hat{x}, \theta)$. Thus the manufacturer will either take optimal or—with a positive probability—underinvest in y.

(ii) Moving one step backwards, the manufacturer will set $\hat{x}$ which minimizes

$$x + \int_{\hat{\theta}(x)}^1 [y^*(x, \theta) + H(x, y^*(x, \theta), \theta)]\, dF(\theta). \tag{A5}$$

That is, the manufacturer expects to bear the cost of the optimal ex post y and the expected harm only if $\theta \in (\hat{\theta}(\hat{x}), 1]$. To determine $\hat{x}$, differentiate Equation (A5) with respect to x:

$$1 + \int_{\hat{\theta}(\hat{x})}^1 \left[\frac{\partial y^*(\hat{x}, \theta)}{\partial x}(1 + H_y(\hat{x}, y^*(\hat{x}, \theta), \theta)) + H_x(\hat{x}, y^*(\hat{x}, \theta), \theta)\right] dF(\theta)$$
$$-\hat{\theta}'(\hat{x}) H(\hat{x}, y^*(\hat{x}, \theta), \theta) f(\theta) = 0. \tag{A6}$$

The proof that the solution to Equation (A6) may be greater than, equal to, or smaller than the solution to Equation (A4) (which determines x^*) proceeds in the similar fashion to the proof given by Craswell and Calfee (1986) in a model incorporating only the choice of x, and is omitted here. ■

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