The Liability Maze

The Impact of Liability Law on Safety and Innovation

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CHAPTER TEN

Liability, Innovation, and Safety in the Chemical Industry

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CHEMICAL products have assumed a steadily increasing role in the U.S. economy throughout this century, contributing to the improvements in the standard of living and the levels of health and safety that America enjoys. At the same time, the fact that the production and use of some chemicals create hazards in the workplace, at home, and in the environment has caused intensified public and private awareness and concern. One mechanism for addressing chemical hazards in this country is tort liability, which permits private parties who sustain chemical injury to seek recovery for damages from the firm responsible.

The purpose of this chapter is to assess the effects of liability for chemical harm, as deployed under the prevailing tort system. In broadest terms, the appropriate measure of the effects is whether liability provides, in some meaningful sense, a net social benefit. For the analysis here, three questions that are related both in theory and in practice need to be considered. Does tort liability for chemical harm promote safety and health? Does tort liability for chemical harm stimulate or inhibit innovation? In trying to control chemical hazards and foster technological advance, does tort liability for chemical harm impose an unacceptably high cost on consumers and industry? (That is, does tort liability for chemical harm result in overdeterrence of chemical risks? Or conversely, are chemical hazards underdeterred by tort liability?)

In this chapter we analyze economic costs and other incentives arising from tort liability that serve to reduce chemical hazards. Our analysis of incentives is performed in the context of innovation theory, which we examine in some detail. To assess whether the safety incentives resulting from liability are excessive or inadequate, we develop an optimal deterrence benchmark, reflecting the total social costs of chemical harm, and

evaluate the liability costs borne by the chemical firm in relation to that benchmark. Chemical harm to workers, consumers, and innocent bystanders are analyzed separately. Despite our general finding of underdeterrence for acute chemical injuries and of gross underdeterrence for chronic diseases from chemical exposure, we provide examples of technological improvements showing that some reduction in chemical hazards is occurring in response to tort liability.

Chemicals and Chemical Activities Covered

Too often, discussions about tort liability consist of little more than sweeping generalizations drawn from anecdotal evidence, even though the effects and effectiveness of tort liability seem to vary dramatically depending on the specific industry involved. Similarly, attempts to introduce global improvements to the tort system are generally ill conceived insofar as the perceived defects or limitations of tort liability arise only in particular markets or under special conditions that can be separately addressed and remedied. An attractive feature of the research for this book, therefore, is its disaggregated nature—the analysis of tort liability conducted by examining specific economic sectors in detail.

The economic sector under consideration here has been officially designated as "chemicals," but the range of chemical products and activities is too broad and contains too many disparate elements to be considered as a whole. Two important chemical areas, in particular, have such distinctive characteristics that they have been omitted from our analysis. The first is pharmaceuticals, which is evaluated by Judith Swazey and Louis Lasagna in chapters 8 and 9. The second is the disposal of hazardous chemical residues or wastes, which has been subject to special liability rules under federal legislation—the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, or the Superfund Act)—and to aggressive regulatory management—especially the federal Resource Conservation and Recovery Act (RCRA), to prevent accidental releases.[1]

Except for those two chemical areas, this chapter examines the effects

1. Even for hazardous waste injuries (as opposed to property cleanup costs), which are not covered by CERCLA, chemical manufacturers have not been held liable for chemical waste damages unless it is a chemical manufacturer's own waste. Thus tort liability for hazardous waste damages should have, at most, an indirect influence on chemical innovation. However, such liability has had a dramatic effect on hazardous waste treatment, storage, and disposal. See Ashford, Moran, and Stone 1989, chap. 2.

of liability from all chemical production and use, to include (primary) chemical manufacture, (secondary) production using chemicals as inputs, and consumer use of chemicals or chemical products. The direct release (but not the disposal) of hazardous chemicals, as part of primary and secondary production activities, falls within the purview of our analysis.

The Tort System and Its Social Context

The tort system is not a simple, homogeneous entity. Its functioning relies on a vast array of attributes, including liability rules (such as negligence or strict liability), rules of evidence (such as the admissibility of evidence and the evidentiary standard), and damage rules (such as award limits and the availability of punitive damages). Furthermore, these attributes are unique for each jurisdiction (the fifty states and the federal courts), and the import of the attributes also depends on their interpretation and application by the particular judge and jury hearing a tort suit.

It is therefore exceedingly difficult to make statements about which liability rules are in effect or to isolate the impact of specific tort system attributes on chemical safety and innovation. With rare exception, we do not attempt to do so here. Instead, we take the existing tort system—and whatever intricate and heterogeneous combinations of attributes compose it—as given and try to assess the effect of the aggregate tort system on chemical innovation and safety. One consequence of this approach is to limit somewhat our ability to identify specific tort system flaws or to recommend detailed modifications of the tort system to enhance its performance. Nevertheless, we do make a qualitative evaluation of tort liability for chemical harm and suggest the direction of change in which improvements to the tort system can be found.

THE OBJECTIVES OF THE TORT SYSTEM. The tort system serves many social purposes; among them are deterrence, compensation, punishment, and justice. *Deterrence* concerns incentives that induce the prevention of damage—here, from chemical hazards—by reducing the production and use of hazardous chemicals, by taking safety precautions in the use of hazardous chemicals, by developing or adopting safer products and processes, or by minimizing the harm once a chemical accident or release has occurred. Deterrence is inherently forward-looking, since it is too late to prevent damage that has already taken place. Thus the objective of deterrence is always prevention of future damage. *Compensation* refers to reimbursing the victim for damages sustained from chemical hazards. Unlike deterrence, compensation is inherently retrospective; reimburse-

ment is for losses caused by past activities. *Punishment* is a burden imposed on wrongdoers to reflect society's condemnation of their reprehensible conduct, the degree of the punishment to be in proportion to the moral gravity of the wrongdoing. Theoretically, the only punitive measure within the tort system is punitive damage awards.[2] Note that punishment and deterrence incentives are intertwined, since punishment imposed for past wrongdoing serves to deter future wrongdoing. *Justice* as an objective is concerned with the institutional process itself, and with the social values it represents, as much as with the specific "outcome" of the process. From this perspective, the tort process has symbolic significance, establishing or confirming personal rights and moral standards.[3]

Among the several social objectives of the tort system, deterrence is most relevant here. Analysis of the effects of tort liability for chemical harm is almost exclusively concerned with the effects on incentives for chemical safety and innovation provided by tort liability. Other objectives, such as punishment, are pertinent only insofar as they also provide deterrence incentives or otherwise affect chemical safety and innovation.

REGULATION AND OTHER MECHANISMS TO ACHIEVE SOCIAL OBJECTIVES. The tort system does not operate in a vacuum. Many other social institutions and mechanisms also influence private sector behavior concerning chemical safety and innovation. For example, other (nontort) causes of action within the judicial system, particularly under contract law and criminal law, also serve to deter hazardous conduct.[4] The dominant source of social involvement in the promotion of health and safety, however, is government regulation, in its broadest sense, by federal and state legislatures and by administrative agencies. Regulatory activities affecting chemical hazards include the following: the promulgation of regulatory standards, such as design standards, health and safety standards, and risk communication standards (for example, product labeling requirements);

2. In jurisdictions where punitive awards are technically forbidden, they may sometimes be disguised as part of jury awards for pain and suffering.

3. For an examination of this function of the tort system, see Mashaw 1985, 1395–96; Elliott 1988, 781–83.

4. Of course, tort law has, in many ways, limited the role of contract law in the area of health and safety hazards (Prosser and Keeton 1984). Some commentators, such as Huber (1988), have gone so far as to conclude that tort liability has spelled the death of risk contracts. Others have argued that reliance on contract law to resolve matters of health and safety was never a workable plan, which, to have been effective, would have imposed astronomical transaction costs. See, in particular, Hager 1989, 572–79; Page 1990, 689–96.

Criminal sanctions may be applied both to individuals in the firm and to the firm itself to punish and deter reckless conduct that places other parties at risk. See, for example, Coffee 1981; Wheeler 1984; Cook 1984.

economic incentives, such as taxes, subsidies, fines, and risk-internalizing charges; price regulation, such as the control of liability insurance rates; information generation and dissemination, such as government-conducted or government-sponsored health and safety research, new technology demonstration projects, and training and education; and specially created administrative systems, such as workers' compensation.

The tort system and regulation interact in complex ways. To some extent tort liability can be viewed as an alternative to regulation. This corresponds to the position traditionally taken by political conservatives: the courts, by enforcing contracts and remedying tortious conduct, serve as an adjunct to the market and ensure its efficient operation. According to this argument, tort liability makes regulation redundant.[5] A related view is that tort liability and regulation are substitutes. Workers' compensation, the provision of which normally bars workers from suing their employers for job-related injuries and illnesses, is a case in point. The situation in which compliance with a regulatory standard immunizes the firm against claims of negligence is another.

Conversely, tort liability and regulation may act as complements.[6] For instance, toxicological and epidemiological research by the government in support of regulatory initiatives may provide critical knowledge about chemical hazards that can be used in tort litigation.[7] Similarly, health and safety standards may confirm that a product is indeed hazardous and thereby open the door to tort liability, especially when a manufacturer was not in compliance with applicable standards. In other situations, tort liability and regulation may intersect—for example, if the regulatory authority formally creates or modifies bases for tort liability for use as its deterrence mechanism (which, as mentioned, occurred by legislative mandate under CERCLA for hazardous wastes). (Another example of the intersection of regulation and the courts, but one not involving tort liability, is the judicial review of regulatory decisions.) Finally, tort lia-

5. It is ironic that the same political conservatives who have traditionally opposed regulation on ideological grounds now support so-called tort reform and embrace regulation as the preferred mechanism for controlling social hazards. See, for example, Huber 1985a, 79–82.

6. For a formal analysis of the conditions under which tort liability and safety regulations should be used jointly, see Kolstad, Ulen, and Johnson 1990.

7. As an example (though outside the chemical sector), epidemiological studies conducted by the federal Centers for Disease Control, central to the plaintiffs' cases, have been accepted by the courts as evidence in suits involving toxic shock syndrome. See *Ellis* v. *International Playtex, Inc.*, 745 F.2d 292, 301 (4th Cir. 1984); *Kehm* v. *Proctor & Gamble Mfg. Co.*, 724 F.2d 613, 619 (8th Cir. 1983).

bility might be seen as part of a just process that transcends regulation. According to this view, the tort system is to some extent a court of last resort. Victims of chemical harm not satisfactorily protected by regulation, and not controlled by voluntary market transactions, are nevertheless permitted under tort law to confront those parties responsible in a courtroom before a jury of their peers.

The important point is that the effects of tort liability rely fundamentally on the prevailing regulatory environment. Even more significant is the fact that the effects of changes in the tort system, ostensibly made to improve it, cannot be determined independently of the regulatory response. Therefore, even though our assessment of the effects of the tort system on chemical hazards and innovation takes the current regulatory environment as given, in evaluating the policy implications of our analysis we must consider the regulatory ramifications as well.

Technological Innovation: A Framework for Analyzing the Effects of Liability

In this section we explore the theory of technological change, which is based on models of firm behavior, and develop a framework for analyzing the effects of tort liability on innovation. The effect of tort liability on chemical innovation and safety is seen to depend on the "amount" of tort liability—that is, on the amount of deterrence tort liability provides. We construct the optimal deterrence benchmark at a conceptual level for subsequent use.

Basic Concepts

Innovation is the first commercially successful application of a new technical idea. Innovation should be distinguished from *invention,* which refers to the formulation of the new technical idea itself, and from *diffusion,* which refers to the subsequent widespread adoption of the innovation by those who did not develop it. Differentiating between innovation and diffusion is complicated by the fact that adopters sometimes alter the innovation in minor ways to suit their specific needs. When these modifications become sufficiently extensive, they may properly be considered a separate innovation.

Innovations can be categorized in several ways. For example, they may be classified according to the degree of technological change: major tech-

nical breakthroughs are termed *radical* innovations, whereas minor technical adaptations are termed *incremental* innovations. An important, basic distinction is that between product and process innovations, the former being a marketable new end product, and the latter a change in the production process.[8]

That innovations are defined as successful commercial applications does not necessarily mean they are inherently socially desirable. If private markets functioned perfectly, then Adam Smith's invisible hand would ensure that each innovation confers a net social benefit. But because of externalities and other forms of market failure, the social desirability of an innovation cannot be guaranteed. New products or processes imposing social costs not reflected in the market, if in excess of their market gain, are "bad" innovations in the sense that society would be better off without them.

The Innovation Process

To assess the effect of tort liability on innovation requires an understanding of the innovation process, including the sources of innovative opportunities, the incentives motivating private agents to engage in innovative search, and the determinants of technological change. The body of literature in the field is vast and largely unsettled, and well beyond the scope of this chapter to review.[9] However, a brief examination of the two main theoretical strands in the innovation literature—only the second of which we embrace—should permit us to identify the salient characteristics of the innovation process.

ORTHODOX THEORY. Consistent with contemporary microeconomic theory, the orthodox (or neoclassical) theory of technological change is grounded on the premise that firms are motivated by a desire to maximize profits. Firms innovate in response to exogenous forces that create profitable technological opportunities. Demand-pull innovations are driven by shifts in market demand or relative prices. Technology-push innovations are developed to take advantage of advances in scientific knowledge whose market value, in the area for which the innovation is being considered, has not previously been determined.

8. A "process innovation" should not be confused with the "innovation process," which is the set of activities by which new products or processes are developed. Innovations, whether of the product or process variety, are the result of the innovation process. See Ashford and Heaton 1983, 110–11.

9. Extensive surveys of the literature on innovation and technical change are provided in Stoneman 1983; National Science Foundation 1983; and Freeman 1982.

Despite its simplicity, profit maximization as an explanation of firm decision rules concerning innovation is a powerful concept. The ability to represent maximization rules using calculus and other mathematical tools has facilitated the construction and testing of sophisticated economic models of technological change. For example, models employing a profit-maximization approach have been widely used to analyze the relation between the resources devoted to innovative endeavors and the rate of innovation, however measured (that is, between the inputs and outputs of innovative activities).

Nevertheless, the orthodox theory of technological change is seriously flawed in its attempt to characterize the innovation process itself. The lack of descriptive realism is obviously part of the problem. Even more important is the inability of orthodox theory to reflect or to address the inherently dynamic quality of the innovation process. Maximization models of firm behavior are static: optimization arises only in equilibrium. The dynamic process through which equilibrium comes about—an essential component of the innovation process—cannot be explained within the context of orthodox theory.[10]

EVOLUTIONARY THEORY. Dissatisfaction with the descriptive and dynamic limitations of orthodox theory stimulated the development of an alternative, evolutionary theory of technological change.[11] According to evolutionary theory, firms are still motivated by profit and will engage in innovative search to exploit perceived profitable opportunities, but profit maximization is not their objective, at least not in any traditional sense. Innovation activities are subject to extreme uncertainty (termed "strong uncertainty"). Besides uncertainty about the precise costs and outcomes of alternatives that might arise in normal economic situations, firms undertaking innovative search are likely to lack knowledge of what the alternatives even are. Maximizing over a set of alternatives loses meaning when the alternatives are not well defined.

Confronted with uncertainty, high transaction costs for acquiring information, and complex real-world problems, firms develop organizational routines—regular and predictable behavioral patterns based on heuristics rather than optimizing decision rules.[12] Organizational routines guide the efforts of firms as they attempt to improve their products and processes. Since those efforts require addressing (typically ill-structured) technical limitations and economic impediments, innovation activity might be broadly viewed as problem solving under conditions of strong uncertainty.

Firms have nontransferable technology-specific skills and institutional traits, such as internal organizational arrangements or external business relationships. These firm capabilities and organizational routines are modified over time as a result of deliberate problem-solving efforts and the good or bad fortune brought about by random events. Because of their capabilities and routines, certain firms will become successful at exploiting specific technological opportunities and translating them into marketable products and processes. Other firms, whose capabilities and routines are less compatible with their economic and technical environment, will become unprofitable (unless blessed by exceedingly good luck during innovative search) and will tend to be weeded out by a market version of natural selection.

Unlike orthodox theory, evolutionary theory portrays technological change as a dynamic process. Not only is innovative search undertaken in response to exogenous market-pull and technology-push forces, but it is endogenously driven by a competitive process whereby firms are continuously improving their capabilities and their products and processes. Uninnovative firms are confronted with the "hidden foot" of competitors willing to take technological risks.[13] The concept of equilibrium, as a stationary point in the innovation process, does not arise in evolutionary theory.

Related Applications to the Chemical Industry

An indication of how dynamic models of the innovation process, embodying evolutionary theory, can be used to evaluate the effects of tort liability on technological change might be provided by examining analogous applications. Of particular relevance are several studies that, using

10. Models of adaptive behavior are an attempt to deal with this problem, but such ad hoc specifications are incompatible with the strict maximization principles of orthodox theory. For further discussion, see Griliches 1967.

11. In reality, what is termed evolutionary theory might more properly be viewed as a collection of related evolutionary theories of innovation (even though Richard Nelson and Sidney Winter have called their research "an evolutionary theory of economic change"). The origins of evolutionary theory probably reside in the work of Schumpeter 1934; 1950. Other, more recent, contributions include Klein 1977, Abernathy and Utterback 1978, and Nelson and Winter 1982. Many of the research developments pertaining to evolutionary theory are discussed in Dosi 1988.

12. The concept of organizational routine embodies many of the ideas of the behavioral theorists, who first suggested that firms "satisfice" in response to problems of bounded rationality. See, for example, Simon 1959 and Cyert and March 1963, which spawned much of this literature.

13. Klein (1977) introduced the notion of "the hidden foot" as an integral part of his model of dynamic efficiency.

the dynamic model of innovation developed by Abernathy and Utterback, assess the influence of regulation on innovation in the chemical industry.[14] These studies indicate that the innovative response to chemical regulation depends on (1) the nature of the regulatory stimulus (for example, what is being regulated, the regulatory mechanism, and the stringency of regulation), and (2) the stage of industrial maturation of the regulated sector, its susceptibility to market incursions from unregulated sectors, and the characterization of the technology at the time of the regulation. The essential point is that the rate and type of innovation arising due to an exogenous stimulus—here, the demand-pull force of regulation—is reasonably predictable.

Several specific findings concerning the effects of chemical regulation on innovation should be mentioned here because, as will be shown, they parallel tort liability effects. First, excessive regulation, regulation that is too stringent from a societal perspective, or otherwise inappropriate regulation increases research and development costs and risks, diverts scarce managerial resources, reduces firm profitability, and thereby discourages investments in research and development and causes the rate of innovation to decline.[15] Second, regulation that is too lax also discourages innovation; instead it elicits adoption of on-the-shelf technology (and usually add-on technology, such as an end-of-pipe pollution control device, that minimizes the technological response of the firm).[16] Finally, stringent (technology-forcing) regulation usually has a positive effect on innovative performance. Although such regulation increases research and development costs, the innovative firm's early scrutiny of health, safety, and environmental effects of new technology increases the success rate of new products and processes brought to market.[17] Furthermore, those innovations that stringent regulation causes to fail because they pose unacceptable health, safety, or environmental hazards are "bad" innovations

14. See, for example, Ashford and Heaton 1983 and Ashford, Ayers, and Stone 1985, as well as the related research cited therein. The Abernathy-Utterback model focuses on the process of industrial maturation of the firm (or productive segment) to explain the rate and nature of innovation. In the initial (fluid) stage, the firm tends to create a market niche by introducing new products that are purchased for their superior performance. During the following (transitional) stage, major process changes occur in response to rising sales and the need to compete on price rather than performance. In the final (rigid) stage, the rate of product and process innovation declines significantly. At this point in its life cycle, the technology is subject to invasion by new ideas or disturbance by exogenous forces, causing a reversion to an earlier stage. See Abernathy and Utterback 1978.

15. Ashford, Heaton, and Priest 1979, 172–78.

16. See, in particular, Ashford, Ayers, and Stone 1985, 463–64.

17. Allen and others 1978, 36–39.

whose market failure should be encouraged. Hence regulation increases the likelihood of both successes and failures in different attempts to innovate. Regulation may also benefit some firms and disadvantage others. Ideally structured regulation may thus cause a shift in the nature of an industry or product line that is precisely what is needed and intended from a societal perspective.

Tort Liability as an Exogenous Stimulus

In terms of the innovation process, tort liability, like regulation, creates market-driven, demand-pull opportunities for technological change. Tort liability is also similar to regulation in the sense that either insufficient or excessive amounts of the exogenous stimulus will discourage desirable innovations, while the "correct" amount will foster socially desirable innovations and discourage others. The ensuing discussion will first explore the logic underlying liability-induced innovation, then address what the "correct" amount of tort liability is, and indicate the role of this tort liability benchmark in the ensuing analysis.

LIABILITY-INDUCED INNOVATION. Tort liability forces the firm to pay for the injuries, illnesses, and property damage for which its products and production activities are responsible (and for purposes of consideration here, for which they are correctly held responsible). From a static market perspective, tort liability must obviously increase business costs and risks by the amount of harm the firm's existing products and processes are deemed to have caused. In addition, product prices will adjust upward to reflect tort liability costs.[18] The net result is that relatively unsafe activities will be less profitable (compared with the situation without tort liability), and some will become unprofitable. These the firm will discontinue.

From a dynamic perspective, the costs imposed by tort liability also represent valuable market information that firms take into account in planning their innovation activities. Tort liability, by adding new safety dimensions to previous design considerations, increases the problem space

18. The dynamics of the market adjustment may, of course, be much more complicated but similar in effect. Assuming a workably competitive industry, product prices will rise by an appropriately weighted average of tort liability costs. Alternatively, differential product risks may result in price spreads favoring safer products. Note that the availability of liability insurance may have a mitigating effect, depending on the ability of insurers to differentiate among product risks.

of the engineer.[19] Furthermore, firms are prompted to enlist the support of toxicologists, epidemiologists, and environmental scientists in the early stages of innovation to assess the safety risks of potential new products and processes, thereby augmenting the firm's technical expertise in developing profitable technological solutions.[20] The activities associated with enhancing and verifying the safety of new products and processes may make innovation more costly, but they also increase the likelihood that the outcome will be commercially successful or have an additional competitive advantage in the longer term.

Thus, correctly applied and properly understood, tort liability provides incentives that both create and destroy market opportunities, but, in general, it redirects innovation toward the development of less hazardous products and processes.

Two related issues should be clarified here. First, even under ideal circumstances, it is possible for the presence of tort liability to discourage the development of an otherwise successful, safe, and desirable innovation. For example, a firm may decide not to initiate the innovation process for a socially desirable product because, hypothetically, the cost of verifying its (actual, but at that time, uncertain) safety exceeds the product's expected profit. Similarly, the higher costs of research and development occasioned by tort liability concerns may reduce the number of innovation initiatives the firm can fund. But unless the firm is held liable for injuries it did not in fact cause, the likelihood of such "perverse" outcomes, and the associated economic loss, must be minimal.[21] The reasons are that (1) the research and development costs attributable to product hazards are usually fairly small, since in the chemical industry *all* the innovation activities through the applied research stage constitute only 17 percent of the total costs of new product development;[22] and (2) the size of the potential market or the per-unit expected profit in the absence of tort liability, or both, must be negligible to be offset by safety R&D costs.

The second issue concerns the appropriate range of innovation activity

19. Allen and others 1978.

20. Many studies of the chemical industry report the contribution to product and process development made by chemical firms' sophisticated analysis of health and environmental risks. See Ashford and Heaton 1983, 133.

21. We argue later in this chapter that such "false positives" are unlikely to occur for the set of chemical firm activities under consideration.

22. Mansfield and others 1971, 118. Furthermore, from 1960 through 1980 research and development expenditures as a percentage of sales steadily declined in the chemical and allied industries, even during periods of intense regulatory activity. See Ashford and Heaton 1983, 115–17.

to be considered with reference to the effects of tort liability for chemical hazards. Ostensibly, the natural choice is new chemical entities: finished products that constitute or contain new chemical formulations, new intermediate chemicals to be used as inputs by nonchemical (secondary) industries, and new basic chemicals to be used in producing intermediate or finished chemical products. The resulting scope of inquiry, however, would be unnecessarily restrictive. A full and complete evaluation must consider all effects on innovative activity throughout the economy, including product and process innovations that entail either the reduction or the elimination of specific chemicals, substitution of less-toxic chemicals or nonchemicals for presently used chemicals,[23] or a change in the mix or control of (existing) chemicals used. Tort liability for chemical hazards can have a positive effect on innovative performance even if the rate of chemical innovation declines, so long as "nonchemical" innovations are sufficiently stimulated.

THE "CORRECT" AMOUNT OF TORT LIABILITY. The way in which tort liability promotes desirable innovations is by internalizing costs; that is, by confronting the firm with the injury costs its activities (would otherwise) impose on other parties. The "correct" amount of tort liability then is simply that level which promotes optimal deterrence, by making the firm bear the entire social costs of the injuries, illnesses, and property damage it causes.

Several features of the optimal-deterrence level of tort liability merit further explanation. First, the social costs to be internalized include both pecuniary costs, such as medical expenses, forgone earnings, and property damage, and nonpecuniary (but real) costs, such as pain and suffering and loss of life.[24]

Second, the "cause" of the harm can itself be a highly controversial legal and philosophical issue.[25] Just to establish a deterrence standard, we assume here that causation can be reasonably determined if all the

23. An example of a nonchemical substitution is using a mechanical pump to replace the CFC delivery system for aerosol sprays.

24. Some analysts (such as Viscusi 1988, 156–57) have noted that less than full compensation is desirable if the injury or illness decreases the victim's marginal utility of income. Furthermore, full compensation for irreplaceable commodities, such as one's life and health, is inefficient (from an insurance perspective), since monetary compensation is, by definition, an ineffective form of reimbursement for these losses (as originally demonstrated in Cook and Graham 1977). The reasoning is correct as far as it goes; but the analysis refers only to optimal *compensation*, which is irrelevant to the objective here of optimal *deterrence*. On deterrence grounds, as noted above, the firm responsible must bear the entire social costs. For further discussion of this point, see Ashford, Moran, and Stone 1989, I-4, I-5.

25. See, for example, Keeton and others 1984; Wright 1985; Landes and Posner 1987.

facts to the case in question are known.[26] Note, however, that the possibility of multiple causes of the chemical harm is not precluded. (Indeed, it is probable.) In cases of multiple causation, we assume that responsibility can be reasonably allocated or apportioned among the various parties involved. For optimal deterrence, the firm should pay only for that proportion of the damages it has actually caused.

Third, to avoid double counting, the damage costs to be incurred by the firm from tort liability should be calculated as a residual, net of the damage payments the firm makes through other means. For example, the workers' compensation benefits and additional salary for accepting more hazardous employment (the wage premium for risk) that workers receive—which constitute a form of ex ante compensation for expected damages caused by the firm—must be taken into account in determining the optimal-deterrence level of tort liability.

Fourth, the costs the firm bears because of tort liability are not restricted to court awards and settlements.[27] They also include the firm's legal expenses to defend the claims, the costs associated with diversion of scarce management and technical skills to respond to tort claims, the premiums paid to insurers to indemnify the firm against damage claims, and any loss of reputation the firm sustains stemming from the tort suits' connotation of fault or wrongdoing.[28]

Fifth, the only exception to full-cost internalization is punitive damages, when the costs borne by the firm may properly exceed the total costs its actions impose on the other party to a particular legal claim. However, the immediate objective of punitive damages is punishment rather than deterrence, the degree of punishment to be in proportion to the moral gravity of the firm's conduct.[29]

26. This assumption is in no way intended to minimize the scientific uncertainty inherent in many cases involving chemical exposure (see, for example, Abraham and Merrill 1986). Note, furthermore, that this uncertainty is not restricted to the tort system. For example, the regulatory process is confronted with the same scientific uncertainty (Latin 1988), and despite putative procedural advantages and superior scientific expertise (Elliott 1985), it is unclear whether administrative agencies are better equipped to deal with it (Elliott 1988, 791–96).

27. For establishing the optimal deterrence standard, it is not relevant what portion of the court award or settlement is received by the plaintiff and what portion by the plaintiff's attorney. All that matters is the total amount of damages paid by the responsible firm.

28. The costs, and associated deterrence value, of loss of reputation can be substantial. For evidence of its importance in the automobile industry, see the chapter by John Graham in this volume. However, in the chemical industry, which is predominantly a supplier industry to other industries, these reputational concerns may not be as important as they are for companies that market consumer products.

29. Although the intellectual foundations differ from state to state, punitive damages are usually intended to punish and to deter simultaneously that tortfeaser and to deter others from doing likewise in the future. Hence the attendant terminology of "exemplary damages" is used in some states. See Ashford, Moran, and Stone 1987, 28–31.

Finally, the preceding delineation of the optimal-deterrence level of tort liability is intended only to serve as a benchmark against which to compare the actual costs firms incur under current tort liability conditions; it is not necessarily a policy recommendation for specific tort liability rules. Thus, for example, reliance on full-cost internalization to promote optimal deterrence does not necessarily constitute an endorsement for strict liability.[30] Similarly, the fact that optimal deterrence dictates having a firm incur liability costs only for that portion of the damages it has caused does not necessarily imply support for introducing a proportional liability standard in the courts.

ANALYSIS USING THE OPTIMAL DETERRENCE BENCHMARK. The rest of this chapter examines the actual tort liability costs firms incur—in relation to the optimal deterrence benchmark for chemical hazards—and the likely incentive effects of those costs on firm behavior.

The analysis of tort liability costs focuses on three elements: the extent to which the firms that cause the damage incur the liability costs (termed "true positives") and vice versa (the extent to which firms that do not cause the damage do not incur liability costs, termed "true negatives"); the extent to which the firms that do not cause the damage incur liability costs (termed "false positives") and vice versa (the extent to which firms that cause the damage do not incur liability costs, termed "false negatives"); and the magnitude of tort liability costs borne by the firm in relation to the optimal-deterrence benchmark.[31]

These elements are obviously a major determinant of chemical safety and innovative performance. Even if industry (as an aggregate) pays for the chemical damages it causes, if individual firms are not confronted with the costs their chemical activities impose on others, they will not be motivated to develop less hazardous products and processes. As a result, in aggregate, the frequency and severity of chemical accidents,

30. In many situations an irresolvable tension exists between two valid concepts of efficient deterrence. One is the level of care, which concerns the safety precautions taken within the context of a given activity and which traditionally has been evaluated by a negligence standard (though a strict liability rule with contributory negligence would serve equally well). The other is the level of activity, which concerns activity choices that maximize social welfare (requiring social costs to be internalized) and which is evaluated on a strict liability standard. See Shavell 1987.

31. See Ashford, Spadafor, and Caldart 1984, 277–79, for more information about the use of true positives, false positives, true negatives, and false negatives in predictive tests.

releases, injuries, illnesses, and property damage are likely to be socially excessive.

Tort Liability and Acute Injuries from Chemical Production or Use

Much of the public concern about tort liability for chemical hazards, certainly as reflected in academic writings, has been limited, either implicitly or explicitly, to *chronic* illnesses from chemical exposure—that is, where there is a fairly long latency period (perhaps as short as several days to a week and as long as several decades) between chemical exposure and the obvious manifestation of disease. Chronic disease can be caused by continuous or intermittent long-term exposure, such as lead poisoning or solvent-related neuropathy, or by short-term or even one-time exposure, leading to cancer or birth defects. Before investigating chronic diseases from chemical exposure, however, we examine *acute* injuries arising from chemical production or use. These are important in their own right and, furthermore, can supply pertinent cost information, as well as serve as a useful comparison, to the subsequent analysis of chronic diseases.

Acute injuries usually arise from a single, discrete episode or accident in which the initial manifestation of the injury is immediate, or nearly so, and the nexus between accident and injury is readily discernible.[32] Highly publicized examples from chemical production and chemical use in manufacturing include the acute injuries and deaths suffered at the 1984 Bhopal disaster in India from exposure to high concentrations of methyl isocyanate (MIC) and phosgene, both highly toxic chemicals, in a runaway chemical reaction, and those suffered from the chemical explosion at the Phillips Petroleum polyethylene plant in Pasadena, Texas, in 1989. Acute consumer product injuries involving chemicals can also be very severe or fatal—in cases of chemical poisonings or explosions, such as from an oven or drain cleaner. Less dramatic and less severe examples of acute injuries to workers, consumers, or innocent bystanders are minor burns or eye irritation from a chemical exposure. Note that acute injuries arising from chemical production need not involve chemicals (for instance, workers at a chemical plant may also sustain cuts from sharp objects or be electrocuted);[33] however, for convenience, we use the term *chemical injuries* to refer to all injuries associated with chemical production or use.

Analysis of the effects of tort liability for acute chemical injuries will consist of the following three tasks: calculating the chemical firm's payout for acute injuries (including transaction costs) relative to the social costs imposed by the injury; assessing the amount of deterrence created by the firm's liabilities, as reflected in the magnitude and nature of the firm's payout for acute injuries; and indicating the probable deterrence effects of liability on chemical safety and innovation. Each of these tasks is disaggregated according to the four possible types of claimant: an employee of the chemical firm, a worker employed in another firm that uses the chemical firm's product as an input, a consumer using the chemical firm's product, or an innocent bystander. Of necessity, estimates of the costs and payouts will be gross approximations, and the appraisal of the amount of deterrence created by liability and its effects on chemical safety and innovation will be qualitative.

Chemical Firm Payout Relative to Social Costs

To determine the amount of deterrence provided by liability for acute chemical injuries, we first identify the main social costs associated with the injuries and estimate what proportion of those costs are incurred by the chemical firm as compensatory damages or in some other form. This comparison of the chemical firm's payout to the social costs of acute injuries can be thought of as a two-step process: a comparison in the case of successful claims, and an assessment of the likelihood that, in an appropriate sense, the chemical firm was responsible for, or caused, the injuries for which it incurs costs—that is, to estimate the likelihood of the claims being true positives.

SOCIAL COSTS AND SUCCESSFUL CLAIMS. The social costs arising from human injury are dominated by the following: the victim's *forgone earnings* from lost worktime, the victim's *medical expenses* for treatment and rehabilitation, the victim's physical *impairment* or loss of function in nonwork experiences and activities, the *pain and suffering* of the victim

32. Consistent with the preceding definition of chronic injury, we shall assume that for acute injuries the delay in manifestation may, in extreme cases, be as long as several days to a week. Obviously the distinction between acute and chronic injuries is not absolute. In ambiguous cases the ability to connect the ailment to its accident source should be the decisive factor in distinguishing acute from chronic injuries for analytical purposes.

33. In principle, the tort liability costs of nonchemical injuries at chemical plants could induce process innovations to reduce accidents or cause the firm to cease chemical production altogether.

and the victim's family, and the losses associated with the victim's *death* (forgone earnings, lost lifetime experiences, and the family's pain and suffering).

The portion of the social costs borne *by* the chemical firm exceeds the compensation the victim or the victim's survivors receive directly *from* the firm. It also includes the payments made by the chemical firm to economic agents, typically insurers, who assume some part of or all of the firm's liability in case of claims against the firm. It is logical to assume that the price paid by the chemical firm to transfer its risks exceeds the expected cost of the claims, since the economic agent will charge a fee for providing the service. But because the chemical firm derives value from eliminating the uncertainty of injury costs and voluntarily enters into such insurance arrangements, a reasonable measure of the social costs of injury borne by the chemical firm is the sum of the claims paid by the firm and its insurers. (The subsequent analysis contains a loading for insurance claims-processing costs for lawsuits.)

EMPLOYEES OF THE CHEMICAL FIRM. When the claimant is an employee of the chemical firm and sustains a job-related injury, workers' compensation statutes usually bar workers from seeking recovery from the employer through common law (except in cases of gross negligence or intentional harm). Workers' compensation programs, funded by the employer's workers' compensation premiums, provide compensation for injuries according to scheduled rates, on a showing that the injury arose out of and in the course of employment, regardless of fault.[34] For acute injuries, such a showing is usually effortless and uncontested.

The percentage of the social costs of acute injury recovered from workers' compensation by the successful claimant is summarized, according to cost category, in the first column of table 10-1. State statutes usually limit wage recovery to two-thirds of lost wages[35] (unadjusted for anticipated wage increases over time or for retirement contributions or health insurance and subject to various constraints on minimum and maximum benefits and benefits duration). The net effect is to reduce the average percentage recovered to somewhat below 67 percent. In principle, workers' compensation covers total medical costs associated with an acute

34. Note that employees may also receive private disability insurance and life insurance benefits from their employer, but these can simply be treated as part of the workers' risk premium (as discussed later).

35. Viscusi 1988, 165. These wage benefits are not taxable, which makes their value to the employee approximately equivalent to net income. This fact, however, does not affect the amount paid out by workers' compensation (and funded by employers).

Table 10-1. *Percentage Recovery of Social Costs from Chemical Firms (and Their Compensated Agents) for Acute Injuries*

	Claimant		
Social cost of injury	*Employee*	*Third party*	*Consumer*
Forgone earnings	67 – [a]	100	100
Medical expenses	100 – [b]	100	100
Impairment[c]	0	100(?)	100(?)
Pain and suffering	0	100(?)	100(?)
Death	10 – [d]	10 – [d]	10 – [d]
Addenda:			
Other possible recovery from chemical firms			
Wage premium for risk	Yes		
Punitive damages		Yes	Yes
Tort system transaction costs borne by chemical firms			
Chemical firms' legal costs	0+	Yes	Yes
Opportunity cost of chemical firms' time	0+	Yes	Yes

Source: Figures derived by the authors from sources indicated in the text.
a. Actual payments are somewhat below 67 percent.
b. Costs are covered but quality of care tends to be minimal.
c. Other than disability.
d. No more than 10 percent and perhaps less than 1 percent of true social costs.

injury, but in practice the quality and level of care provided tend to be minimal.[36] Workers' compensation provides payment for disability, which reflects the socioeconomic consequences of impairment (a strictly medical concept), but normally only insofar as earning power is affected.[37] In that sense, disability payments actually should be classified as part of forgone earnings that extend into the future. However, workers' compensation does not provide benefits for impairment itself or its nonwork consequences; nor does workers' compensation provide recovery for pain and suffering.[38]

Workers' compensation does award death benefits to the employee's survivors, ranging from $70,000 to about $200,000 in most states,[39] but these benefit levels are a minute fraction of the corresponding social cost. Estimates of the valuation of loss of life, based on individuals' willingness to pay for an incremental reduction in risk—which current economic

36. Viscusi 1988, 172.

37. Barth and Hunt 1980, 125–26.

38. The magnitude of these uncompensated nonpecuniary health impacts is not negligible. Viscusi and Moore (1987, 258) derive willingness-to-pay estimates for pain and suffering and impairment (nonwork disability) that equal 1.1 to 1.5 times the valuation of pecuniary losses associated with job injuries.

39. U.S. Chamber of Commerce 1990.

thinking argues is the appropriate conceptual basis for valuing risks to life—have consistently exceeded $1,000,000; most such estimates place the value of human life at more than $3,000,000; and a few estimates exceed $10,000,000.[40] Recent research using more accurate data on job-related fatalities concludes that workers collectively place a value of from $5,000,000 to $6,500,000 (in 1986 dollars) per "statistical" life saved,[41] and these estimates do not include all aspects of the social cost of premature death. Furthermore, federal agencies concerned with health and safety have typically selected a value per statistical life saved in the millions of dollars as a basis for their regulatory decisions. For instance, the Environmental Protection Agency used a loss-of-life estimate of $3,000,000 in its 1987 regulatory impact analysis of protection of stratospheric ozone—and was then criticized for having selected too low a value.[42] By comparison, death benefits from workers' compensation provides no more than 10 percent, and perhaps less than 1 percent, of the social cost of death.

In sum, chemical firms pay, through workers' compensation premiums, 75 percent or more of the social cost of minor acute injuries (entailing little pain and suffering), and pay approximately 50–67 percent of the social cost of acute injuries of average severity (where there is some pain and suffering but no impairment). Because of limits on awards, workers' compensation pays some 10–50 percent of the social cost of severe acute injuries (with appreciable pain and suffering and impairment) and from 1–10 percent of the social costs of fatal acute injuries.

Workers' compensation, however, is not the only mechanism through which chemical firms incur costs for their workers' acute injuries. To attract workers to perform work that is more hazardous than the average job, chemical firms must offer higher wages.[43] The risk-compensating wage premium employees receive represents a type of ex ante payment by the firm for expected future injury costs. However, for workers to demand a risk premium to offset otherwise uncompensated job hazards, they must have knowledge of the firm-specific and activity-specific risks that confront them, they must be able to process the risk information in a rational manner, their demands must incorporate the interests of their family and friends (to avoid externalities), and the relevant job market must be competitive (otherwise they will be unable to express their demands effectively). Each of these assumptions is unrealistic to a greater or lesser degree,[44] but at least for *acute* chemical hazards—in which the consequences of accidents are immediate—the employees are likely to be cognizant of many of the more serious risks. As a result, one expects that many, but not all, of the "residual" social costs of acute chemical injuries (that is, those not compensated by workers' compensation) are paid out by the chemical firm in the form of wage premiums for risk.

There are no other costs of any consequence that the chemical firm incurs as the result of its employees' acute injuries. The transaction costs of the workers' compensation system are low in the case of acute chemical injuries because the source of the injury is usually obvious and rarely contested. Chemical firms therefore do not generally bear legal expenses or tie up management or technical staff in resolving these injury claims.

40. Viscusi (1986, 201) provides a review of the empirical work in the area and suggests that the estimates under $1,000,000 (conducted in the 1970s) either depend on questionable assumptions or are not representative of the general population. (In addition, even these estimates would exceed $1,000,000 in current dollars.) For a more critical view of the estimation procedures used in deriving a value per statistical life saved, and the assumptions on which they are based, see Ashford and Stone 1988, 2–29. The problems they enumerate include (1) the presence of externalities and imperfect information, which violate the assumption of perfectly functioning markets, and (2) model misspecification, errors in variables, and sample bias, which undermine much of the econometric work. Some of these problems clearly result in an underestimation of the value of loss of life.

41. See Moore and Viscusi 1988b. A "statistical" life is merely a linear extrapolation of an individual's willingness to pay for a small reduction in risk. For example, suppose workers demand an extra $0.01 an hour for more hazardous work, with an increased annual risk of a fatality of 1/200,000. On an annual basis (assuming 2,000 hours of work a year), workers will each receive an extra $20 in return for accepting the risk. If 200,000 workers perform the more hazardous work, they will collectively receive $4 million and, on average, one of these workers will die as a result. Thus, in this example, $4 million is the imputed value of a statistical life, based on individual workers' risk decisions entailing small risks to life.

42. See U.S. Environmental Protection Agency 1987, app. G-9. For criticism of the dollar value, see, for example, Ashford and Stone 1988, 29–38.

43. See, however, Graham and Shakow (1990), who argue that a dual or segmented labor market exists. According to them, most high-risk jobs are competed for in the secondary labor market, which is characterized by low wages, poor working conditions, and no discernible compensation for risk.

44. Consider, for now, problems with the perfect information assumption. First, even if employees are familiar with the toxicity and reactive properties of the chemicals they work with, they are unlikely to know the hazards associated with the plant design or with plant operations that potentially threaten but do not include them. Second, it is well documented that individuals have serious risk-perception problems. (See, for example, Tversky and Kahneman 1974, 1124–31; Machina 1987, 141–47.) In principle, individuals are just as likely to overreact as underreact to hazard information, but in practice worker risk perception appears to be dominated by an "it-can't-happen-to-me" syndrome, which results in known risks being understated and therefore undervalued. See Ashford 1976a, 357.

Finally, being a no-fault system, workers' compensation does not award punitive damages.

In sum, the chemical firm's total payout for the acute injuries of its employees is less than the social costs arising from those injuries—how much less depends largely on the severity of the injury and on the relative efficiency of the job market in internalizing job hazards through wage premiums for risk.

INNOCENT BYSTANDERS AND CONSUMERS OF CHEMICAL PRODUCTS. The share of the social costs of acute injuries borne by the chemical firm—again, in cases where the claimant is successful—is virtually identical for two types of claimant: an innocent bystander (one who has no pertinent economic or contractual relationship with the chemical firm whose activities or product caused the injury) and a consumer injured by a chemical product.[45] Both types of claimant try to obtain recovery by bringing tort action against the chemical firm.

Successful claimants receive the full compensation to which they are entitled from the chemical firm (and its insurers) for all forgone earnings and medical expenses associated with the acute injury.[46] The 100 percent recovery for these social costs is presented, for innocent bystanders and consumers, respectively, in columns 2 and 3 of table 10-1. However, the average liability awards in death cases—including both court awards and out-of-court-settlements—is under $220,000,[47] which is less than 10 percent of the associated social cost, even assuming a value for a statistical life of only $3,000,000.

Presumably, successful tort claimants are fully compensated by the chemical firm for the social costs of impairment and pain and suffering brought about by the acute injury. Nevertheless, the fact that average liability awards in death cases are more than an order of magnitude below their social cost casts doubt on the comprehensiveness of impairment and pain and suffering awards, which—like the valuation of loss of life—

45. Note that these two types of claimants are not treated as equivalent in subsequent analysis.

46. Both innocent bystanders and consumers may also sustain property damage as the result of an acute chemical accident. We assume claimants receive full recovery for these damages, but, to avoid unnecessary complications, we have not included them in the ensuing analysis.

47. The average awards in death cases were derived from both court awards and out-of-court settlements in product liability suits concluded in 1977. The source of the figure (as reported in Viscusi 1988, 173) is Insurance Services Office 1977, 113, adjusted to reflect price increases to 1985 values using the consumer price index. (Unfortunately, the ISO study has not been updated, and other data sources, such as Jury Verdict Research, Inc., 1991, are biased upward because they do not include out-of-court settlements.)

might be considered somewhat subjective.[48] Thus one might reasonably anticipate that juries which award successful claimants less than 10 percent of the death benefits that economic research suggests they should will correspondingly award less than full impairment and pain and suffering damages, and perhaps substantially less.[49] Because of their subjectivity, we grudgingly retain the 100 percent figures but accompany them in table 10-1 with a question mark to reflect our doubts.

Even assuming 100 percent recovery of impairment and pain and suffering costs, the chemical firm's compensatory payments are less than 40 percent of the social costs arising from acute injuries. The reason is that fatal injuries make up such a large share—at least 70 percent, under conservative assumptions—of the total social costs of acute injuries.[50] If

48. However, as mentioned earlier, Viscusi and Moore (1987) have derived willingness-to-pay estimates for pain and suffering and impairment that exceed the pecuniary losses from injury by 10 to 50 percent.

49. One possibility, admittedly untested, is that juries award damages predominantly on the basis of pecuniary losses. That would explain the considerable undercompensation—relative to social cost—in death awards: juries are basing damages primarily on the casualty's discounted future earnings. If that is so, juries are likely to seriously undercompensate impairment losses as well, by treating them as workers' compensation does, as disability benefits for future loss of earning capacity. In that case, the impairment itself and its nonwork consequences would go largely uncompensated. Evidence concerning the magnitude of compensation payments for disability and impairment, being developed by Hensler, promises to shed some light on this matter. Telephone conversation on August 14, 1990, with D. Hensler, Rand Corporation.

50. Data from the Insurance Services Office 1977, 113, indicate that fatal injuries, while comprising only 3.6 percent of the death award cases, account for 18.8 percent of total liability award payments. But, as previously shown, those death awards represent less than 10 percent of the corresponding social cost. Even taking an upper bound of 10 percent, implying the value of a statistical life of $2,200,000, fatal injuries constitute 70 percent of total social injury costs, of which the chemical firm's compensatory payments make up less than 40 percent. For a value of loss of life of $3,000,000, fatal injuries' share of total social injury costs rises to above 75 percent, and the chemical firm's compensatory payments falls to below 30 percent of total social costs. For a value of a statistical life of $5,000,000—a recent lower-bound estimate derived from significantly improved fatality statistics (Moore and Viscusi 1988b)—fatal injuries account for 84 percent of total social injury costs, and the chemical firm's compensatory payments cover less than 20 percent of total social injury costs.

Two possible qualifications in the use of the Insurance Services Office data come to mind. First, the data were derived from product liability cases of all types. Possibly the composition of tort suits involving acute injuries from chemical products and those involving innocent bystanders will be significantly different, but we have no reason to believe that is the case. Of course, insofar as tort suits for acute chemical injuries consist of a larger percentage of fatalities, the share of total injury costs covered by the chemical firm's compensatory payments will decline even further. The second qualification is that liability awards have increased since 1977. (For example, Jury Verdict Research, Inc., 1991, found that the average jury award for a wrongful death of an adult male in 1989 was $1,057,612, but that

impairment and pain and suffering costs are, in fact, incomplete, then the chemical firm's compensatory payments constitute an even smaller share of the social costs of acute injuries.

Compensatory damages are not the only tort costs borne by the chemical firm. Successful claimants may be awarded punitive damages from the firm.[51] On average, trial awards for punitive damages are equal to approximately 25 percent of compensatory damages.[52] But on the basis of very rough estimates, post-trial appeals and settlements reduce punitive damage awards to from 8 to 19 percent of compensatory damages.[53] Using the larger figure of 19 percent and recalling that compensatory damages paid by the chemical firm constitute only 40 percent of acute injury costs, we gauge that punitive damages paid by the firm are equal to approximately 8 percent of acute injury costs.

Chemical firms also incur transaction costs to defend against tort claims. Here we include transaction costs for all claims filed against the chemical firm, both successful and unsuccessful (from the view of the claimant).

figure is not representative of all classes of fatality or all liability cases, since settlements are not included. Moreover, the figure will usually include medical expenses incurred by the victim before death. All these factors will tend to bias the reported figure upward relative to the true average.) However, even if awards for fatal injuries were to rise to $1,000,000, assuming the value of a statistical life is $5,000,000, the chemical firm's compensatory payments would still constitute less than 40 percent of total injury costs. To offset the possibility of this effect, we have used a very low value of loss of life in the text.

The reader can verify the preceding results by applying these two formulas: (1) $C = P_I + mP_D$, and (2) $S = (P_I + P_D)/C$, where P_I is total nondeath compensation; P_D is total death compensation; m is the ratio of the true social cost of statistical deaths to death compensation; C is the total social cost of acute injuries (fatalities included); and S is the share of social injury costs covered by the chemical firm's compensatory payments.

51. Recall, however, that punitive damages are, strictly speaking, not intended as an offset to the social costs of injury, but as a punishment for the firm's outrageous conduct.

52. This estimate was reported in U.S. General Accounting Office 1989, 29, based on the GAO's study of product liability lawsuits. Punitive damages are rarely awarded. A Rand Corporation study concluded, "Punitive damages continue to be rarely assessed in personal injury cases, and most frequently are assessed against defendants who were found to have intentionally harmed plaintiffs. In most of these cases the damages were modest." Peterson, Sarma, and Shanley 1987.

53. U.S. General Accounting Office 1989, 45–47, indicates that after appeal the defendant's damages were reduced to 76 percent of the trial award in cases without punitive damages and to 40 percent of the trial award in cases with punitive damages. Furthermore, in the second instance, almost all of the reduction came from punitive damages. From this information alone, we can calculate, crudely, that punitive damages amount to only 12 percent of compensatory damages after appeal. However, the relative size of the appealed to the not-appealed cases and of the appealed punitive damage cases to those without (information not fully obtainable from the data) could alter the percentage somewhat in either direction.

Legal fees and expenses have been estimated to equal about 30 percent of compensatory damages, which translates to about 12 percent of acute injury costs.[54] The chemical firm also bears the opportunity cost of management and staff time spent in contesting claims, other nonlegal expenses, and claims-processing costs (including insurance claims-processing costs) for lawsuits. These have been estimated to be 22 percent of compensatory damages, which is equivalent to about 9 percent of the social cost of acute chemical injuries.[55]

Taking into account compensatory damages, punitive damages, and all transaction costs associated with defending against tort claims, the total costs borne by the chemical firm—for claims filed by innocent bystanders and for product liability claims—constitute just below 70 percent of the social cost of acute chemical injuries. Even this estimate may be too high. It depends on a fairly low value of loss of life and full recovery by the claimant for impairment and pain and suffering. And it ignores the effects of statutory caps on awards and award exclusions (such as punitive damages), which serve to limit the chemical firm's payout even further.[56]

EMPLOYEES OF OTHER FIRMS. Finally, the claimant may be a worker employed by another firm (a firm other than the chemical firm) that uses the chemical firm's product in its business activities. If so, the percentage of the social costs of acute injuries incurred by the chemical firm depends on which of three actions the claimant takes.

First, the worker may file a workers' compensation claim. In that event, the costs borne by the employer are identical to those calculated

54. Kakalik and Pace (1986, 115) calculate that the defendant's ratio of average legal fees and expenses to average compensation, for organizations in nonautomobile tort litigation, is 32 percent in state courts and 18 percent in federal courts. Since most litigation takes place in state courts, a composite 30 percent ratio seems appropriate. Data in U. S. General Accounting Office 1989, 53, suggest a ratio of about 33 percent for product liability cases settled by trial verdicts. Since most product liability claims were reported as being resolved in pretrial settlements, which required much lower legal fees and expenses, an adjustment to 30 percent is not unwarranted. Third-party claims by innocent bystanders might have lower legal fees because the question of comparative negligence is not at issue; however, that effect is largely negated by the fact that the purchase of the chemical product comes with an implied warranty, breach of which gives rise to a cause of action.

55. See Kakalik and Pace 1986, 74, for summary data from nonautomobile tort suits.

56. The effect of caps and exclusions for particular award categories, however, is surely diminished somewhat by the ability of the jury to shift benefits it feels are justified (but statutorily barred) to another award category. Thus, for example, the statutory exclusion of punitive damages may in some cases simply result in inflated pain and suffering awards. Furthermore, some juries may increase the size of the award to offset (their expectation of) the legal fees a sympathetic plaintiff must pay.

earlier for chemical firms whose employees file workers' compensation claims. The only difference is that the employer of the injured worker, rather than the chemical firm, bears those costs.

Second, the worker may file both a workers' compensation claim through his employer and a product liability suit against the chemical firm whose product caused the job-related injury. (Although workers' compensation statutes prohibit workers from filing tort claims against their employers, they are not barred from bringing a tort action against a "third party," such as the chemical firm.) The situation regarding the chemical firm is no different from the product liability claims just analyzed. The total burden on the chemical firm and the employer, however, is normally less than the sum of its parts. Under typical workers' compensation arrangements, a worker who recovers in full from a third party and also receives workers' compensation awards must reimburse the employer for associated payments made by the employer into workers' compensation.[57] Nevertheless, both the employer and the chemical firm bear part of the social cost associated with the worker's acute injury. The employer still pays the worker a risk premium to perform more hazardous work, while the chemical firm incurs product liability costs constituting about 70 percent of the social costs of the acute injury.

Third, the worker may file only a product liability suit against the chemical firm whose product caused the job-related injury. However, this situation leads to the same shared burden between the chemical firm and the employer as when the worker files both for workers' compensation and tort damages. The employer still pays ex ante expected injury damages in the form of wage risk premiums, and the chemical firm incurs liability costs amounting to about 70 percent of the social costs of acute injuries.

We note, for subsequent analysis of deterrence effects, that while the chemical firm's liability burden is less than the total social costs arising from the acute injury, the costs incurred by industry as a whole theoretically could exceed total injury costs when the worker collects from third parties. That outcome, however, is subject to the earlier qualifications about whether tort liability actually supplies complete compensation for impairment and pain and suffering and whether wage premiums provide full reimbursement for residual risk.

57. In addition, a few states allow third parties successfully sued by workers under product liability to seek proportionate reimbursement from a *negligent* employer. The effect of this legal option is clearly to reduce the chemical firm's burden. But because this situation is the exception rather than the rule, we do not include it in the subsequent analysis.

TRUE AND FALSE POSITIVES; TRUE AND FALSE NEGATIVES. Up to this point, analysis of the burden of acute chemical injuries borne by the chemical firm has assumed that the firm's payout was purely for the acute injuries it caused. We now examine that assumption.

For employees of the chemical firm or employees of other firms seeking recovery for job-related acute chemical injuries, one can argue that workers' compensation awards are almost always based on valid claims. Acute chemical injuries immediately manifest themselves, and the links from the acute injury to the workplace chemical product or activity to the *employer* are apparent. Some workers may exaggerate the effects of an injury, but that possibility is offset by the fact that others choose not to or are encouraged by their employers not to file a claim at all.

For reasons similar to those just mentioned, tort claims seeking recovery for acute chemical injuries filed by innocent bystanders are generally meritorious, though here the patent connections are from the acute injury to the injury-causing product or activity to the *chemical firm* responsible. The same logic applies with almost equal force to product liability suits filed by employees of other firms or consumers claiming acute chemical injuries. The main complicating factor in a product liability action is the need to determine which liability criteria are relevant to the specific facts in the case and then to apply those criteria judiciously. But we know of no evidence to suggest that the courts have failed in carrying out this charge in cases involving acute chemical injuries or, more generally, that meritless claims for acute chemical injuries are a problem.

Two elements of chemical firm costs arising out of tort liability also need to be addressed within the context of meritorious claims. The first is punitive damages. On the surface, it is difficult not to acknowledge that the magnitude of jury awards for punitive damages is often unpredictable and perhaps occasionally inconsistent from case to case. At the same time, evidence exists that appellate courts have been generally successful in correcting the errors made in the lower court and in narrowing the degree of unpredictability in punitive damages.[58] Moreover, one must remember that the immediate objective of punitive damages is common justice, including punishment for socially reprehensible conduct. Ques-

58. See, for example, U.S. General Accounting Office 1989, 47. However, the subjective nature of what constitutes socially unacceptable conduct and what punishment is appropriate in response makes an objective benchmark difficult to define, much less apply. Therefore, what may be characterized as an "error" on appeal might, on occasion, be more accurately described as substituting the appellate court's values and preferences for the jury's.

tions of efficient deterrence are, at best, of secondary importance where punitive damages are concerned.[59]

The second cost element to be addressed is transaction costs. It is possible, though inaccurate, to argue that having the chemical firm (the defendant) bear its own legal costs and other tort-related expenses for the cases it wins represents a type of false positive.[60] The flaw in this reasoning is that before the verdict by the court, the success or failure of the plaintiff's claim is not certain or known by the parties to the suit.[61] Transaction costs are merely the price one pays to obtain social justice: they are the costs of using the tort system to obtain a just decision rather than costs to be decided through the tort process.

The Degree of Deterrence

As mentioned earlier, of the several objectives of the liability system, deterrence is the most relevant to concerns about stimulating the adoption or development of safer products and processes. The liability costs stemming from chemical harm provide a signal to the chemical firm and to other private actors to engage in hazard prevention activities.[62]

The deterrence effects of the liability system need to be examined with great care. From an economic perspective, optimal deterrence is achieved by the internalization of all social costs of chemical production and use. In general, overdeterrence may arise if costs that exceed or are unrelated to the social costs are imposed on private actors. However, we argue that

59. By analogy, one would not excuse convicted criminals from imprisonment just because they would be more productive out of jail.

60. A parallel argument for the successful defendant would be equally wrong. In principle, however, one might argue somewhat differently: that the high transaction costs deter injury victims from filing valid tort claims and result in false negatives. In the case of acute chemical injuries, for which establishing causation is usually not an issue, such arguments would appear to be groundless.

61. By analogy, the risk premium workers receive for undertaking a hazardous job is an ex ante mechanism for reducing uncertainty. If analyzed only after the job is done, however, one might conclude, again incorrectly, that the injured workers were undercompensated and the uninjured workers overcompensated. The point is that at the time the risk premium was paid, it was not known which of the workers would be injured.

62. This is one of the essential lessons to be derived from the earlier examination of the innovation process. Acquiring information and engaging in innovative search are costly to the firm. The uncertainty of liability costs attracts the attention of management and redirects its activities to exploit profitable safety opportunities that arise from the avoidance of these tort system costs. Liability awards not only bring to the attention of industry the advantages of minimizing the hazardous effects of technology but also raise the importance of safety in technological planning in general.

the imposition of punitive damages should not be confused with overdeterrence, because those damages serve a moral and symbolic function, satisfying a need for just punishment of wrongdoers. Good-faith and knowledgeable chemical firms have little to fear from punitive damages, because it is highly unlikely that such damages would be imposed on them. Nevertheless, the specter of punitive damages not only encourages good-faith industrial activity but also prods the firm to gain the knowledge required to assess the risks of its technology.

Many factors influence the firm's response to the expected value of economic costs associated with chemical harm, such as the role of insurance, the extent to which the firm produces a diversified mix of products, and the desire of the firm to maintain its reputation as a good corporate citizen.[63] Table 10-2 presents some possible scenarios for the firm under which it feels varying degrees of motivation to engage in hazard-reducing activity, including the search for safer products and processes.

Firms that are fully insured for worker injuries through workers' compensation have little incentive to engage in preventive activities, beyond an interest in reducing the wage premium for risk that workers demand; the only exceptions are those rare cases where compensation premiums are a high percentage of the cost of doing business and the firm is merit-rated.[64] The same is true for injuries to consumers for chemical firms insured by product liability insurance,[65] and for injuries to others for chemical firms insured through enterprise liability insurance. Through its risk-spreading properties, insurance shifts the total social costs of chemical damage away from the firm, causing underdeterrence. As regards

63. One important factor, not usually relevant for *acute* chemical injuries (except perhaps in Bhopal-sized accidents), is the size of the chemical firm's assets in relation to the magnitude of its tort liability burden and the ease with which the firm can evade that burden by seeking bankruptcy protection.

64. Only the very largest firms, representing about 15 percent of employees, are self-insured. (However, many of the larger chemical firms fall into this category.) The remaining firms are either class rated, based on industrywide safety and health performance, or experience rated, which is a class rating adjusted by the individual firm's safety and health record. Payments by these firms into workers' compensation are only loosely related to the costs their employees' injuries and illnesses impose on the system. See Ashford and Caldart 1991, 228.

65. However, the fact that product liability insurance has become exceedingly expensive in recent years, and often become unavailable, has forced many firms to self-insure. These consequences of the insurance "crisis" have generally served to stimulate risk-prevention incentives (though they may be accompanied by some efficiency losses as well). See, for example, Abraham 1986, 14–16, and Ashford, Moran, and Stone 1989, V-6.

Table 10-2. *Motivation for Developing or Adopting Safer Products and Processes*[a]

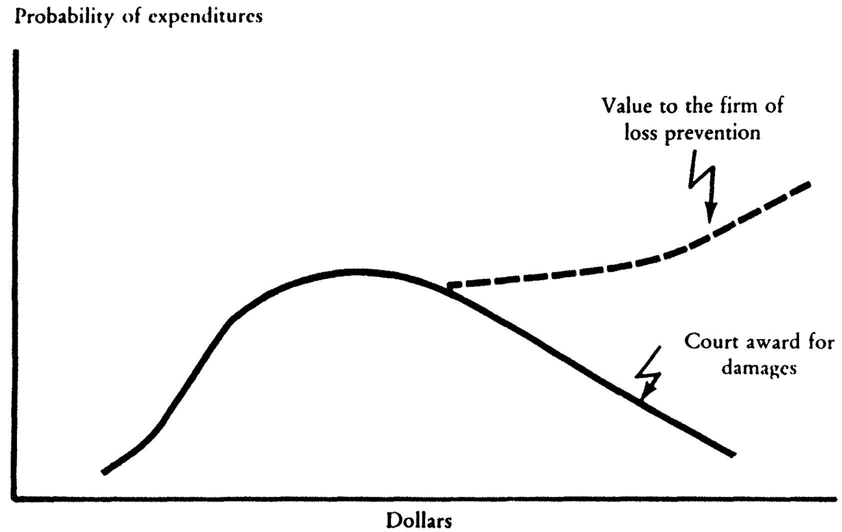
	Economic costs from compensating damage awards					
	Expected losses					
Item	*All firms*	*Self-insured firms with many products or hazards*	*Reasonably likely upper bound to losses for self-insured firms with few products or hazards (risk averse)*	*Punitive damages*	*Reputation*	*Likely overall incentives*
Under insurance						
Workers' compensation (workers)	--			(+)[b]	+	–
Product liability (consumers)	(–)[c]			+	+	+
Enterprise (others)	(–)[d]			+	+	+
Without insurance						
Workers		+	+ +	+	+	+ +
Consumers		+	+ +	+	+	+ +
Others		+	+ +	+	+	+ +

a. -- denotes great underdeterrence; –denotes some underdeterrence; + denotes slight deterrence; + + denotes modest deterrence, but still less than optimal.
b. Available as a surcharge in a minority of jurisdictions.
c. Possibly unavailable or very expensive.
d. Possibly available for injuries; unavailable for chronic disease.

worker injuries or enterprise liability, the incentives that do exist for insured firms are probably directed to limiting the effects of an accident once it occurs (such as providing fire extinguishers) rather than to preventing it in the first place.[66] Furthermore, minimal loss prevention advice originates with the insurance carriers, who usually lack the requisite technical and scientific expertise to suggest technological changes

66. However, some, though incomplete, deterrence is provided even if the chemical firm has product liability insurance, since many consumers recognize and value safety features and are willing to pay extra for them. Similarly, chemical firms with workers' compensation and enterprise insurance are still motivated to prevent safety hazards that threaten to damage or destroy their own property (though that is usually insured as well). Finally, the terms of most insurance policies contain some deterrence features of their own, such as coinsurance and deductibles, but these clearly are of secondary importance.

Figure 10-1. *Probability of Court Awards and Resources Devoted to Prevention by the Risk-Averse Firm*



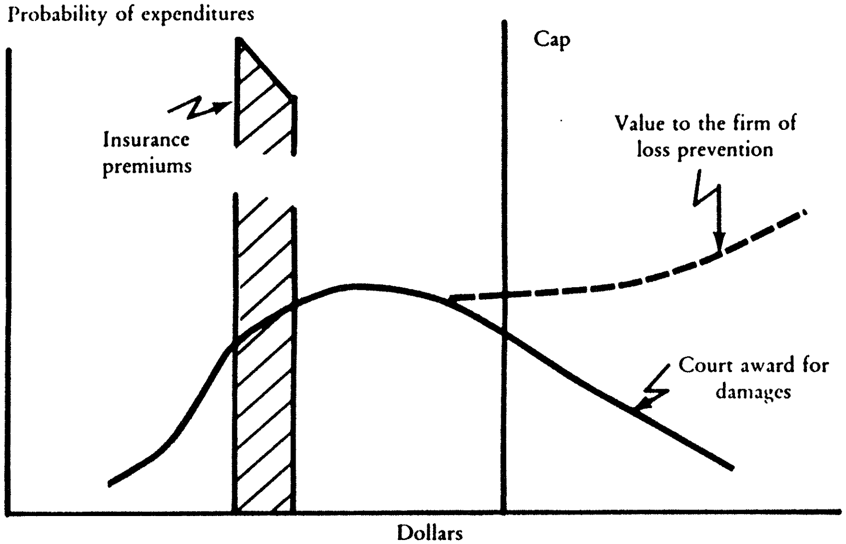
in chemical products and processes.[67]

As for chemical firms that manufacture many chemical products, the expected value of economic losses due to chemical harm to workers, consumers, and bystanders provides a degree of deterrence, at least insofar as the firms are not insured and must self-insure. For the uninsured chemical firm that manufactures few products, it is the reasonably likely upper bound of a loss, rather than the expected value of the loss, that drives the firm's preventive activities. This extra incentive reflects the risk averseness of those firms against business disruption and sudden catastrophic economic loss. Such firms will go an extra measure to prevent chemical harm, but that should not be confused with overdeterrence. Rather, when firms are insured, there is underdeterrence.

In figure 10-1, the smooth curve depicts the *hypothetical* probability

67. "Insurers have little knowledge of the loss-prevention or loss-protection technologies available to the insured chemical handlers. Interviews with underwriters reveal little interest in developing their own knowledge base about either technologies or losses." (Katzman 1988, 86.) But the recent development of risk retention groups, group captives, and other user-financed insurance mechanisms promises to improve risk management skills and to provide a payoff for the firms that participate. See Ashford, Moran, and Stone 1989, V-5, V-6.

Figure 10-2. *Probability of Court Awards and Resources Devoted to Prevention by the Risk-Averse Firm (Illustrating the Effects of Insurance and Caps on Awards)*



of an award as a function of its size. The value to the firm of avoiding damage is identical with this curve for small awards. As awards increase in size, the risk-averse firm will increasingly value risk reduction and will spend increasing amounts to avoid liability, as shown in the dashed curve.[68] The capping of awards (shown as a solid vertical line in figure 10-2) or risk spreading through insurance (where premiums are collected, as shown by the hatched area) decreases the risk averseness of the firm and, hence, expenditures for developing or adopting safer products and processes.

Attempts to avoid liability claims (with or without the possibility of punitive damages) may drive either an uninsured or an insured firm to take special efforts for prevention. If so, the firm is responding not only to its expected economic losses but also to the value *it* places on maintaining a good reputation. Poor corporate images are avoided by good corporate citizens. Expenditures incurred by firms to develop safer products or processes may exceed the expected value of losses for not doing

68. One possible functional relationship is:

$$V = px\,(d + k_1 d^2 + \ldots + k_n d^{n+1}),$$

where V is the value to the firm of avoiding damage costs; p is the probability of damage; and d is the severity of damage. The firm's risk averseness is reflected in the higher-order terms of this expression.

so or even the reasonably likely upper bound of a loss. That too should not be attributed to overdeterrence, since the firm *values* the avoidance of liability beyond the immediate or monetizable economic costs. Similarly, risk-averse firms that decide not to market or use unsafe products or processes may do so because they value the avoidance of liability risk more than the net profits that might have been enjoyed. If the firms that decide not to market unsafe products or to use unsafe processes do not have the intellectual resources to develop new technology, they may suffer economically. However, other firms—notably new entrants—may develop new technologies and profit from them.

As we determined in the previous analysis, the liability system does not impose on the chemical firm even the expected value of the social costs of acute chemical injuries. Rather, it provides an underdeterrence for the development of safer products and processes. But though there is underdeterrence from an economic perspective, the deterrence that does occur because of prospective liability tends to promote safer technologies for those firms that value "doing the right thing."[69] Ensuring that the economic costs associated with acute chemical hazards are fully internalized would create even greater incentives.

Safety and Innovative Performance Related to Tort Liability

Although, as we have just concluded, tort liability provides inadequate deterrence in the area of acute chemical injuries, the tort system—in many cases, in combination with regulation—has stimulated the development of safer products and processes. For example, consumer products with potentially explosive containers (such as some former drain cleaners) have been removed from the market and replaced by safer alternatives, and almost all chemical products contain detailed warnings and instructions about their safe use so as to inform and protect the consumer.

The evidence of liability-induced chemical innovations is probably greatest in the area of process technology, but most of those innovations are incremental (though valuable) ones, and because of underdeterrence

69. For these firms, liability operates much like regulation, in the sense that factors beyond economic considerations stimulate them to engage in a search for better products or processes. For example, an impending ban on a product encourages certain firms to develop substitute products. In the context of tort suits, the possibility of punitive damages or a damage to reputation also stimulates the search for new products and processes, even though the economic factors associated with those damages might not in and of themselves stimulate a search for new products.

many have not been widely adopted as yet. Examples of incremental process innovations include the removal or reduction of toxic chemicals used in the manufacturing process, improved chemical containment technology, and the development of user-friendly technology that can tolerate less than ideal human performance without initiating a chemical accident.

Partly in response to the Bhopal disaster—both because of the risk of massive tort liability and because of the regulatory activities that were themselves initiated partly in response to what happened in Bhopal[70]—chemical firms and secondary manufacturers have reduced the amount of hazardous chemicals they store on site and, in some instances, the amounts they use. For example, at a plant in Texas that makes methylene di-paraphenylene isocyanate, Dow Chemical Company has reduced by 95 percent its inventory of phosgene, one of the deadly gases released in Bhopal. At its New Jersey facility, Hoffmann–La Roche has totally eliminated the use of phosgene by switching to ethyl chloroformate, which reacts similarly but is not as toxic, and PPG Industries has recently developed carbonyldiimidazole, a benign phosgene substitute that can be used in the synthesis of pharmaceutical products. Similarly, Monsanto modified an acrylonitrile process to remove hydrogen cyanide storage (in tanks with a capacity of 375,000 pounds); now the hydrogen cyanide is consumed as feedstock by units that produce lactonitrile and other materials. Monsanto also substituted the less-volatile aqueous ammonia at atmospheric pressure for pressurized anhydrous ammonia at its plant in Dalton, Georgia. As a final example, Dupont removed several chlorine-filled rail cars formerly parked at a siding at its plant in Edgemoor, Delaware; chlorine is brought in only when it is needed.[71]

An example of improved chemical-containment technology is the use, by Monsanto and Hercules, Inc., of 150-pound and 300-pound cylinders to store chlorine rather than the conventional 10,000-pound tanks. Similarly, Hoffmann–La Roche shifted from 12,000–15,000 gallon tanks to 2,000 gallon tanks.[72] Also, there have been significant innovations involving chlorine valves on chlorine railcars—such as corrosion resistance and a pneumatically operated, automatic-shutoff mechanism—but these

70. The most prominent example is title III (the Emergency Planning and Community Right to Know Act of 1986) of the Superfund Amendments and Reauthorization Act of 1986 (SARA), which has imposed significant reporting requirements on industry concerning the identity and amounts of hazardous materials stored, used, and released and has created several emergency planning mechanisms as well.

71. For further discussion about the preceding examples, see Zanetti 1986.

72. Zanetti 1986, 27–28.

valve design improvements have only rarely been adopted in the United States.[73] Examples of user-friendly technological developments include spiral-wound gaskets (to replace fiber gaskets), expansion loops (to replace bellows), articulated arms (to replace hoses), and bolted joints (to replace quick-release couplings).[74] Finally, an example of a radical process innovation is Union Carbide's development in 1977 of a safer technology for manufacturing linear, low-density polyethylene. The Union Carbide technology is capable of functioning as a "swing" reactor, shifting to the manufacture of high-density polyethylene—the product being manufactured at the Phillips Petroleum plant in Pasadena, Texas, at the time of the 1989 explosion. The Phillips technology is a low-pressure, slurry-phase polyolefin process; the Union Carbide technology is a low-pressure, gas-phase fluidized-bed process that does not contain polymer settling legs, which were the site of and a necessary condition for the Phillips explosion.[75] Again, the issue is the rate of adoption of these technological improvements in safety, which greater deterrence would promote.

Tort Liability and Chronic Chemical Illnesses

Our analysis of the effects of tort liability for chronic chemical diseases parallels the tasks performed in the preceding analysis: an estimation of the chemical firm's payout for chronic diseases relative to the social costs of those diseases; an assessment of the amount of deterrence created by these chemical firm liabilities; and an evaluation of the deterrence effects of liability for chronic chemical diseases on chemical safety and innovation. Because much of the groundwork was provided in the evaluation of liability for acute injuries, the following analysis is greatly simplified.

Recall that chronic disease may develop weeks to years after initial exposure to a toxic chemical. Examples of chemical-caused disease are cancer of all organ systems; respiratory diseases including emphysema; reproductive system damage including sterility, impotence, miscarriages, and birth defects; heart disease; and neurotoxicity. Many of these chronic

73. Hunter 1988.

74. See Kletz 1989, 18.

75. Several other factors have been suggested as probable causes of the Phillips explosion, including the use of inexperienced subcontractors, faulty maintenance procedures, and defective mitigation equipment. Nevertheless, that type of explosion would not have been possible in the Union Carbide reactor. See Mark 1986, 425–54; U.S. Department of Labor 1990; MacKerron 1989.

diseases caused by chemical exposures are considered "ordinary diseases of life." Hence, unless there is strong epidemiologic evidence linking exposure with excess incidence of these diseases in the workplace, in a specific geographic area, or associated with a particular consumer use, causation is extremely difficult to establish in either the tort or administrative compensation systems now in operation.

Sometimes chronic diseases constitute so-called signature diseases, which are so rare that, as a practical matter, their incidence can be explained only by exposure to a specific chemical. Examples are angiosarcoma (liver cancer), associated with vinyl chloride exposure, and mesothelioma, associated with asbestos exposure. In some instances the presence of the chemical causing an ordinary disease of life can be ascertained, for example lead in blood and other tissues, or DNA-adduct formation that is chemically specific.[76] In these cases chemical causation may be unequivocally established as a result of biological monitoring.

Chemical Firm Payout Relative to Social Costs

Consistent with the preceding analysis of acute chemical injuries, we evaluate the chemical firm's payout relative to the social costs of chronic diseases in two steps: we first estimate the firm's payout relative to social cost for successful claims and then assess whether, in an appropriate sense, the chemical firm was responsible for, or caused, the diseases for which it incurs costs (and conversely, whether the firm did not cause diseases for which it does not incur costs).

SOCIAL COSTS AND SUCCESSFUL CLAIMS. The portion of the social costs of chronic chemical injuries borne by the chemical firm can be most easily evaluated when compared with the firm's payout for acute chemical injuries. Subject to three important qualifications, the costs incurred by the chemical firm *in cases where the claimant is successful* are approximately the same for acute chemical injuries and chronic chemical diseases (of a given severity).[77]

76. Ashford and others 1990.

77. We are able to dismiss a potential fourth qualification. Because chronic diseases typically arise years or decades after the chemical exposure, it seems appropriate to discount the associated damages to their present value. For example, Moore and Viscusi perform this procedure in calculating the value of life for long-term risks (Moore and Viscusi 1988a; Viscusi and Moore 1989). But since chemical firms are able to defer payment of damages until after the disease manifests itself, these costs must also be discounted by a similar amount. Therefore, for purposes of evaluating deterrence effects, the two discounting procedures cancel each other and need not be performed.

The first qualification is that, because of the difficulty of establishing causation, chronic disease claims are much more likely to be contested and the legal effort required during litigation will usually be much greater than for acute injury claims. As a result, the chemical firm's transaction costs related to chronic disease claims will be larger, even for signature disease claims, which usually have the best chance of establishing causation. For example, legal expenses in workers' compensation death claims based on exposure to asbestos have been estimated as 14 percent of compensation payments, and defendants' legal costs in asbestos product liability suits have been estimated as 58 percent of payments to plaintiffs.[78] Although we do not have comparable data for the average disease claim, evidence from workers' compensation gives some indication of the associated transaction costs. Employers are six times as likely to contest a disease-related claim as they are an injury-related one. Those disease-related claims in which compensation is eventually paid are often hotly contested; indeed, 60 percent of such awards were initially denied.[79]

The second qualification applies only to disease-related cases in which the claimant is a worker. The risk-compensating wage premium that workers receive will typically be smaller for chronic chemical hazards than for acute chemical hazards for several reasons: the etiology of many chemically related diseases is still unknown or not well understood; many of these chronic hazards are not widely publicized in the workplace;[80] and the chronic disease consequences of chemical exposure are normally not obvious, because they are not immediate (since the latency period between chemical exposure and manifestation of disease may last decades). Presumably for these reasons econometric estimates of risk-compensating wage differentials are invariably based exclusively on acute-injury data. Some, albeit imperfect, evidence of the small risk premium workers receive for chronic chemical hazards exists for one class of asbestos victims, asbestos insulators, for whom 44 percent of deaths during 1967–76 were due to asbestos-related disease. The premium for risk they received was estimated as approximately 4.5 percent of their wages, which over their lifetime had a

78. Boden and Jones 1987, 339; Kakalik and others 1983, viii. Note that most of these asbestos claims involve non-signature diseases, such as lung cancer.

79. Viscusi 1988, 169.

80. However, Viscusi and O'Connor (1984) suggest that, on the basis of survey evidence measuring the effectiveness of chemical hazard labeling, workers have a widespread awareness of many of the chemical risks confronting them.

present value of under $10,000 (about $15,000 in 1985 dollars).[81] These figures suggest that the total risk-compensating wage differential received by asbestos insulators per statistical life was only $34,000 (in 1985 dollars).

The third qualification concerns the possibility that the chemical firm will be unable to pay disease-related damages—a situation that normally does not arise for acute chemical injuries. Two characteristics of chronic diseases from chemical exposure account for the difference. First, the potentially lengthy latency period between chemical exposure and manifestation of the disease raises the prospect that the chemical firm will no longer be in business by the time a claim is filed. Second, chronic chemical hazards are capable of affecting a very large number of people. Even if the chemical firm is still in business, it may not have set aside sufficient funds, purchased sufficient insurance coverage, or have sufficient assets to cover the flood of tort claims, possibly totaling billions of dollars. The ease with which firms can seek protection from tort claims through reorganization under federal bankruptcy laws further diminishes the damages that claimants are able to collect.[82]

What is the net effect of these qualifications on the share of chronic injury costs borne by the chemical firm in cases where the claimant receives compensation? First consider employee claims through workers' compensation. Even among those cases of occupational disease in the United States for which workers' compensation is provided, the average award is only an estimated 13 percent of the average wage loss caused by occupational disease.[83] After increasing this amount by an additional 14 percent to reflect the cost of contesting claims, the chemical firm's total costs incurred through workers' compensation for chronic disease are still only 15 percent of the associated wage loss, and therefore no more than approximately 1 to 2 percent of the total social costs of those diseases.

81. See Barth 1983. However, Boden and Jones (1987, 337) suggest that Barth's estimates may not be representative of the wage premium for chronic chemical hazards. They propose that the low figure was not due to complete lack of knowledge about asbestos risks, since the workers in question were part of active health studies. They argue, rather, that the cause was imperfect competition in the industry. The market power of the insulators' union raised wages (ignoring risk) 15 to 30 percent above those for comparable workers. The resulting lack of comparable job opportunities at an elevated wage level induced the insulators to work with asbestos without receiving a significant risk premium.

82. When questions of insolvency arise, so that the firm's available assets must be apportioned among existing and potential claimants, one consequence, of course, is to drive up transaction costs. The bankruptcy filings of several major asbestos manufacturers is one reason the transaction costs for asbestos-related claims are so large.

83. U.S. Department of Labor 1980, 4.

For tort claims, evidence from asbestos cases, though not conclusive, suggests the costs borne by the chemical firm due to chronic disease. For product liability claims involving asbestos worker deaths, the average mean payment for worker deaths during 1967–76 was approximately $100,000 (in 1985 dollars); the payment level increased dramatically during that period, reaching a peak for 1975–76 deaths of approximately $125,000 (in 1985 dollars).[84] If we use the peak figure, and increase it by 58 percent to reflect the defendant's legal costs and by another 22 percent to reflect other transaction costs,[85] the total tort costs borne by the chemical firm in asbestos-related deaths is $225,000, or no more than 10 percent of the corresponding social cost.

Finally, suppose that both a workers' compensation claim and a tort claim are filed for an asbestos-related death and that, in addition, the chemical company bears the cost of the risk-compensating wage differential received, ex ante, by the worker. The average discounted value of workers' compensation payments involving asbestos worker deaths was $47,000 (in 1985 dollars);[86] increasing that amount by 14 percent for legal costs yields a total payout of $54,000 per claim. Adding the $225,000 per tort claim, the $54,000 per workers' compensation claim, and the $34,000 of risk premium received per asbestos worker (insulator) death yields a total cost of $313,000 borne by the chemical firm per *compensated* asbestos worker death, a sum that is no more than 5 to 15 percent of the corresponding social cost.

TRUE AND FALSE POSITIVES; TRUE AND FALSE NEGATIVES. The chief difference between chronic diseases and acute injuries, as reflected in the portion of total social costs borne by the chemical firm, resides not in the smaller average payout to successful claimants in chronic disease cases but in the the fact that most chronic diseases from chemical exposure are false negatives: the chemical firm responsible does not incur any liability costs at all.

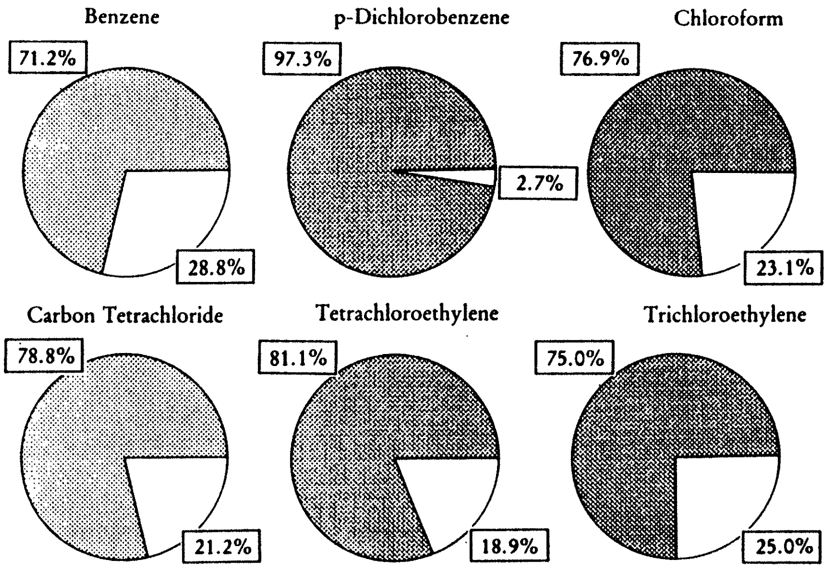
Both direct and indirect evidence shows that the number of illnesses associated with chemical exposure is significant. In the early 1970s the

84. These figures are provided in Boden and Jones 1987, 334–35, in 1982 dollars; they were converted into 1985 dollars using the consumer price index. The Rand Corporation study of compensation received by asbestos victims in product liability claims reports that the average recovery for all such claims of asbestos-related disease and death is approximately $37,000, in 1985 dollars (Kakalik and others 1983). However, the composition of the health effects associated with this estimate is not known.

85. Kakalik and Pace 1986, 73.

86. These figures are provided in Boden and Jones 1987, 339, in 1982 dollars; they were adjusted to reflect price increases to 1985 values using the consumer price index.

Figure 10-3. *Indoor-Outdoor Cancer Risks*[a]



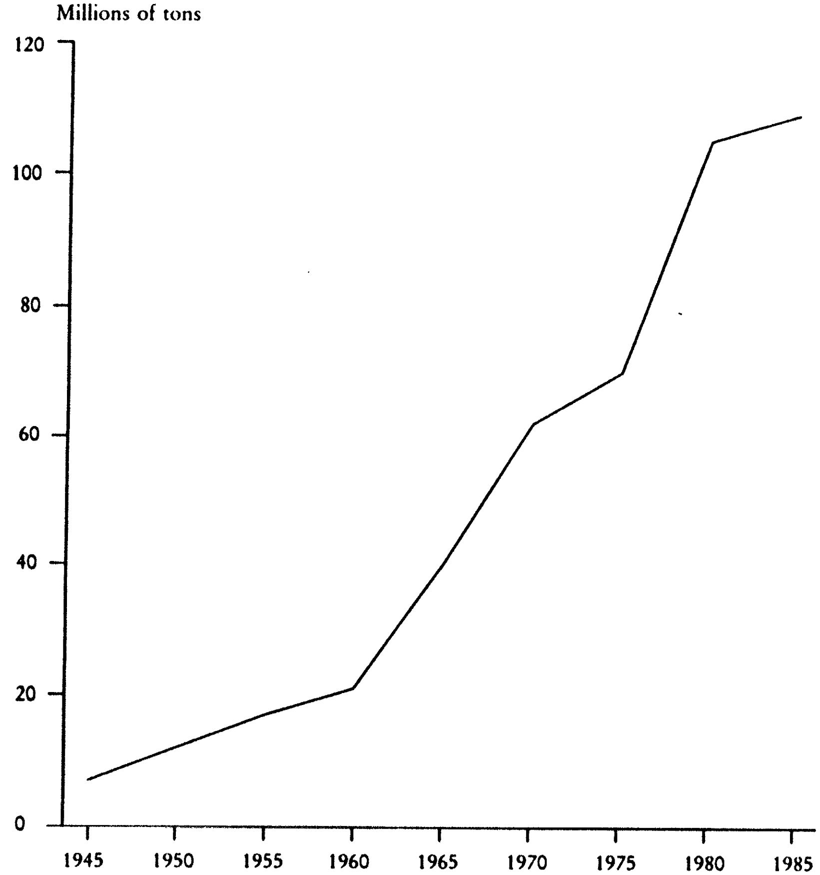
Source: Lance Wallace, Environmental Protection Agency, Office of Indoor Air.
a. The white area in each circle represents outdoor cancer risks; the darker area represents indoor cancer risks.

public health service estimated that there were as many as 100,000 deaths due to occupational disease and 390,000 cases of new occupational illnesses annually.[87] Although these figures were initially contested, independent evidence shows that the figures are essentially correct. In 1965, 27,000 cases of occupational disease were reported in California.[88] Extrapolated to the nation, this implies 336,000 cases of occupational disease annually. A recent study of occupational disease in New York state estimates conservatively that there are 5,000–7,000 deaths each year and at least 35,000 new cases of occupational disease.[89] Extrapolation to national figures yields a tenfold increase that, again, is in line with the estimates twenty years earlier.

Clearly occupational exposure is the greatest source of risk from exposure to chemicals. Lower-level exposures, but equally serious in terms of the number of people affected, are indoor exposures to chemicals in the home and office from consumer and industrial products and building materials. Figure 10-3 presents the relative percentages of the risk of cancer for six commonly found carcinogens, demonstrating that nonindustrial indoor air exposure is a greater risk than outdoor air exposure.

87. Pollack and Keimig 1987, 79.
88. Ashford 1976b, 3.
89. Markowitz and Landrigan 1989, 10.

Figure 10-4. *Synthetic Organic Chemical Production in the United States, 1945–85*



Source: U.S. International Trade Commission.

Given that the production of synthetic organic chemicals has risen dramatically since World War II (see figure 10-4), it is no surprise that the number of chemically related chronic diseases has grown. For example, cancers of organ systems that can clearly be related to chemical exposure are on the rise.[90] Similarly, cases of asthma have experienced a sharp, unexplained growth in number. Finally, new problems related to multiple chemical sensitivities have been increasingly noted.[91] In sum, though the actual magnitude of occupationally and environmentally caused chronic disease is debatable, the problem is clearly significant.

90. See Schneiderman, Davis, and Wagener 1989; Vineas and Simonato 1991.
91. See, for example, Ashford and Miller 1991.

The requirement in both the workers' compensation system and in the courts—that it be more likely than not that a particular disease of a particular worker was caused by an exposure to a particular hazard—leaves most occupational and environmental disease uncompensated.[92] Of the 300,000 to 400,000 cases of new occupational diseases annually, only 3 percent are reported in workers' compensation records.[93] The Department of Labor concluded that only 5 percent of *serious* occupational disease received benefits through the workers' compensation system.[94] Cancer associated with occupational exposure is of special concern to workers. Table 10-3 lists the industrial processes causally associated with human cancer, and table 10-4 those cancers associated with occupational exposure. Conservative estimates attribute 4 percent of all cancer deaths in the United States to workplace exposures.[95] Using this figure, Caldart has estimated, however, that only one out of every seventy-nine occupational cancer victims in the United States receives workers' compensation, which represents a compensation rate of 1.3 percent.[96] Even in the case of asbestos—the most celebrated and obvious source of occupational disease—workers' compensation claims were filed for only 36 percent of asbestos-related deaths, and tort claims were filed for only 16 percent of those deaths.[97]

Combined with the preceding estimates of chemical firm payouts in successful chronic disease cases, these figures show that even for highly publicized signature diseases the firm incurs no more than 5 percent of the corresponding social cost. For the average non-signature disease, the chemical firm burden is less than 0.1 percent of the corresponding social cost.

Before examining the associated safety incentives, we need to dispose of one additional issue: false positives. Does the chemical firm incur nonnegligible liability costs for meritless cases—in which the claimant's chronic disease is unrelated to the chemical firm's products or activities? A review of successful claims—involving asbestos or Agent Orange primarily, or in rare instances industrial emissions (recall, not including hazardous wastes)—suggests not.

92. See, for example, Caldart 1985, 94–96.
93. Ashford 1976b, 11.
94. U. S. Department of Labor 1980, 3.
95. Doll and Peto 1981, 1194. Many researchers, however, have criticized the 4 percent figure for occupational cancer as being greatly underestimated. See, for example, Schmahl, Preussman, and Berger 1989; Axelson and Forrestiere 1989.
96. Caldart 1985, 94.
97. Boden and Jones 1987, 335–38.

Table 10-3. *Industrial Processes Causally Associated with Human Cancer*

	Target organ	
Exposure	*Human*[a]	*Animal*
Aluminum production	Lung, bladder (lymphoma, esophagus, stomach)	No relevant data
Auramine, manufacture of	Bladder	Mouse, rat: liver (auramine, technical grade)
Boot and shoe manufacture and repair	Leukemia, nasal sinus (bladder, digestive tract)	No relevant data
Coal gasification	Skin, lung, bladder	No relevant data
Coke production	Skin, lung, kidney	No relevant data
Furniture and cabinet making	Nasal sinus	Inadequate evidence (wood dust)
Hematite mining, underground, with exposure to radon	Lung	Inadequate evidence (hematite); rat, dog: lung (radon)
Iron and steel founding	Lung (digestive tract, genitourinary tract, leukemia)	No relevant data
Isopropyl alcohol manufacture, strong-acid process	Nasal sinus (larynx)	Inadequate evidence (isopropyl oils)
Magenta, manufacture of	Bladder	Inadequate evidence (magenta)
Painters (occupational exposure as)	Lung (esophagus, stomach, bladder)	No relevant data
Rubber industry	Bladder, leukemia (lymphoma, lung, renal tract, digestive tract, skin, liver, larynx, brain, stomach)	Inadequate evidence

Source: Tomatis and others 1989, 796.
a. Suspected target organs in parentheses.

Table 10-4. *Chemicals and Groups of Chemicals Causally Associated with Human Cancer for Which Exposure Has Been Mostly Occupational*

Exposure	*Target organ*	
	Human[a]	*Animal*[a]
4-Aminobiphenyl	Bladder	Mouse: liver, bladder; rat: mammary gland, intestinal tract; rabbit, dog: bladder
Arsenic and arsenic compounds[b]	Skin, lung, (liver, hematopoietic system, gastrointestinal tract, kidney)	Mouse, hamster: (lung, respiratory tract)
Asbestos	lung, pleura, peritoneum, gastrointestinal tract, larynx	Rat: Lung, pleura, peritoneum (mesothelioma); mouse: peritoneum; hamster: pleura, peritoneum
Benzene	Leukemia	Mouse: lymphoma, lung, zymbal gland; rat: various sites, including zymbal gland, oral cavity
Benzidine	Bladder	Mouse: liver; rat: zymbal gland, mammary gland; hamster: liver; dog: bladder
Bis(chloromethyl) ether and chloromethyl methyl ether (technical grade)	Lung	Mouse: lung, local, skin; rat: lung, nasal cavity; hamster: (respiratory tract)
Chromium compounds, hexavalent[b]	Lung (gastrointestinal tract)	Mouse: local; rat: lung
Coal-tars	Skin, lung (bladder)	Mouse: lung, skin, local; rat: lung; rabbit: skin
Coal-tar pitches	Skin, lung, bladder (gastrointestinal tract, leukemia)	Mouse: skin
Mineral oils, untreated and mildly treated	Skin (respiratory tract, bladder, gastrointestinal tract)	Mouse, rabbit, monkey: skin
Mustard gas (sulfur mustard)	Lung, larynx, pharynx	Mouse: (lung, local)
2-Naphthylamine	Bladder (liver)	Mouse: liver, lung; rat, hamster, dog, primates: bladder
Nickel and nickel compounds[b]	Nasal sinus, lung (larynx)	Mouse, rat, hamster, rabbit: local; rat: lung
Shale-oils	Skin (colon)	Mouse: lung, local; rabbit: local
Soots	Skin, lung	Mouse: skin, local; rat: lung
Talc containing asbestiform fibres	Lung (pleura)	Inadequate evidence
Vinyl chloride	Liver, lung, brain, lymphatic and hematopoietic system (gastrointestinal tract)	Mouse: liver, mammary gland, lung; rat: liver, zymbal gland; hamster: liver, skin, forestomach; rabbit: lung, skin

Source: Tomatis and others 1989, 797.

a. Suspected target organs in parentheses.

b. The evaluation of carcinogenicity to humans applies to the group of chemicals as a whole and not necessarily to all individual chemicals within the group.

Consider claims related to asbestos exposure, for example. Criticism of asbestos awards have been raised on two fronts. First, in *Beshada* v. *Johns-Manville Corporation*,[98] the New Jersey Supreme Court, adopting a strict liability standard, refused to consider the "state-of-the-art" defense raised by the defendant—that the defendant was not capable of warning the plaintiffs of the dangers of asbestos because those dangers could not have been known at the time of the plaintiffs' exposure. Holding the chemical firm liable for hazards that were truly unknowable fails to promote deterrence, since, as a matter of logic, the firm could not reasonably take precautions against unforeseen harm. However, evidence from other asbestos suits demonstrated that asbestos suppliers not only knew of the risks of asbestos but acted to suppress information about those risks.[99] Therefore, the state-of-the-art defense would properly have been rejected under a negligence standard.[100] The second criticism is that most smokers harmed by asbestos could have prevented the harm by not smoking.[101] One might therefore infer that smoking, not asbestos, was the likely cause of their subsequent disease. But such an inference would be unwarranted. With lung cancer, for example, the risks relative to a nonsmoker not exposed to asbestos (whose risk is normalized at 1) are 5 for a nonsmoking asbestos worker, approximately 10 for a smoker not exposed to asbestos, and approximately 50 for a smoking asbestos worker.[102] Therefore, for nonsmokers, asbestos exposure raises their risk of lung cancer fivefold (from 1 to 5); for smokers, asbestos exposure also raises their risk of lung cancer fivefold (from 10 to 50). Thus both smoking and nonsmoking asbestos workers can attribute 83 percent of their lung cancer cases to asbestos exposure.[103]

The Agent Orange case was a class action suit filed by U.S. soldiers exposed to the herbicide Agent Orange, which contains minute traces of the deadly poison dioxin. Hours before the trial was to begin, the claims against the seven chemical company defendants were settled for $180

98. *Beshada* v. *Johns-Manville Prods. Corp.*, 90 N.J. 191, 202, 447 A.2d 539, 545 (1982).

99. See, in particular, Brodeur 1985 and Page 1987, 1331–36, for a review of the evidence.

100. Furthermore, the New Jersey Supreme Court's holding that a defendant could be liable for failing to warn of an unknowable risk has been limited to asbestos cases and has not been adopted in other jurisdictions. Page 1990, 668.

101. Huber 1985b, 300.

102. Selikoff 1981, 23.

103. Note, therefore, that in terms of the optimal deterrence benchmark, only 83 percent of the associated harm should be borne by the chemical firm.

million.[104] Some have criticized the Agent Orange suit as meritless, arguing that there was no association between the plaintiffs' diseases and exposure to the herbicide. In fact, in approving the settlement, Judge Jack Weinstein candidly admitted that the plaintiffs probably could not have provided sufficient proof of causation to win their case in court.[105] Nevertheless, for two persuasive reasons the costs incurred by chemical firms in the Agent Orange case do not qualify as a false positive. First, the issue, in terms of the optimal-deterrence benchmark, is not whether the association between exposure to Agent Orange and a subsequent disease is sufficient to sustain a more-likely-than-not evidentiary standard, but whether any association exists at all. The degree of association determines the share of the social costs that the chemical firms should bear. Second, new scientific evidence has demonstrated a significant statistical association between exposure to Agent Orange and non-Hodgkin's lymphoma, soft tissue sarcoma, skin disorders, subclinical hepatotoxic effects, and porphyria cutanea tarda, as well as some statistical association between exposure to Agent Orange and Hodgkin's disease, neurologic effects, and reproductive and developmental effects.[106] From this evidence, the chemical firm payout for Agent Orange claims is only a minute fraction of the corresponding social costs, not an instance of a false positive.[107]

Finally, the chemical firm occasionally incurs liability costs for claims of bodily harm associated with its industrial emissions. However, most of these successful claims are for signature diseases in which traces of the toxic chemical were found in the claimant's blood or other tissue,[108] and therefore are not false positives. The chemical firm may also receive an isolated product liability claim, alleging a chronic hazard associated with the chemical product. We do not know whether some of these are nuisance

104. Huber 1988, 62.

105. In *re Agent Orange Product Liability Litigation*, 597 F. Supp. 740,755 (E.D.N.Y. 1984).

106. Agent Orange Scientific Task Force 1990.

107. Another issue, not considered here, is whether the federal government should have been immune from liability claims involving Agent Orange. We note, however, that at the time of this writing, the Veterans Administration has sued the federal government for the first time in its history, for the government's failure to acknowledge and compensate the victims of Agent Orange exposure adequately.

108. An example is the case against Gulf Resources and Chemical Corporation in which the plaintiffs alleged that emissions from the firm's smelter had caused high levels of lead in their bloodstreams. The claims were settled out of court. See BNA, "Environmental Reporter," April 15, 1983, p. 2321 (computer file, Bureau of National Affairs, Washington).

suits without merit, but they are only infrequently, if ever, successful. Indeed, for the chemical products and activities covered, what we found remarkable about the associated liability claims was the absence of industry "horror stories."

The Degree of Deterrence

That the total liability costs borne by the chemical firm for chronic diseases from chemical exposure represent no more than 5 percent, and often less than 0.1 percent, of the corresponding social costs suggests that the liability system provides gross underdeterrence, even before the dampening effects of insurance are factored in.

The sources of this extreme underdeterrence include difficulties in verifying chemical exposures, difficulties in demonstrating an association between exposure and subsequent disease by a preponderance of evidence, and difficulties in identifying the responsible firm or industry. The often lengthy latency period between exposure and manifestation of disease exacerbates these difficulties and introduces other problems as well, including legal obstacles, such as statutes of limitation, and the prospect that the firm responsible will have ceased operation before a claim is filed or, if still in business, will have insufficient assets to cover incoming claims. Another problem related to the long latency between exposure and manifestation of disease concerns management incentives. Insofar as management performance is judged by its short-run contributions to corporate profitability,[109] safety investments will appear uneconomic, since the firm's investment costs arise immediately but the benefits from chronic disease reduction may not appear for decades. In effect, corporate management, as a result of its myopic incentives, may try to externalize the costs of chronic health hazards to its successors.

Even for signature diseases, many of these same difficulties apply if the latency period between chemical exposure and manifestation of disease is long. Therefore, there is significant underdeterrence for those diseases as well. However, when subclinical effects of exposure to chemicals give rise to a cause of action (or when the presence of the toxin in the body unequivocally establishes exposure to a specific chemical), liability in the tort system may be pursued before the manifestation of disease and may be successfully established. The opening up of tort liability for subclinical effects and exposure per se has generated some degree of risk averseness

109. Siliciano 1987, 1844–46; Ashford and Caldart 1991, 230.

in many firms, gradually leading them to substitute less toxic chemicals or to change chemical processes.

For non-signature diseases, however, when clearly no opportunity for a successful tort action (or for workers' compensation awards) will arise,[110] very little deterrence exists at all. The one promising source of deterrence for non-signature diseases is the chemical firm's concern that future scientific advances will establish unique links between its products or activities and chronic diseases, effectively transforming what were formerly considered to be ordinary diseases of life into signature diseases.

Causation remains a major problem in establishing the connection between exposure and disease in the context of worker exposure, but even more so in the context of consumer exposure, particularly to common chemical substances such as benzene. A worker might possibly establish a claim for benzene-related leukemia, for example, in the context of industrial exposure, but the consumer is exposed to benzene in so many different ways—in filling his automobile with gasoline and in using consumer products and solvents—that it would be extremely difficult to establish that his leukemia was related to a particular chemical firm's product.

Safety and Innovative Performance Related to Tort Liability

Because the tort system normally provides gross underdeterrence in the area of chronic disease from chemical exposure, liability plays only a minor role in stimulating the development of less chronically hazardous chemical products and processes. Examples of process safety improvements are the replacement of organic solvents—such as trichloroethylene, a possible human carcinogen—with water-based cleaners and the use of less toxic material, or smaller quantities of toxic material, in electroplating activities.[111] But these changes in technology are probably stimulated more by regulatory prodding, particularly restrictions on the disposal of hazardous wastes, than by liability concerns. Furthermore, the adoption of these technological improvements is still not widespread.

A well-known furniture polish is an example of a chemical product whose safety improvement might properly be attributed to liability concerns. The original formulation of the polish contained 97 percent nitro-

110. Indeed, the high transaction costs and poor chances of success confronting potential plaintiffs usually discourage them from even filing valid claims.

111. See, for example, Ashford and others 1988.

benzene. Possibly, if a significant excess of cancer were found in consumers of that product, the manufacturer might be swamped with liability suits that the claimants stood a good chance of winning. Whatever the motivation, the product was quietly reformulated without regulatory action or attention.

Obviously when the safety of a chemical is called into question by either regulation or litigation, the firm has every incentive to retain its market by modifying the final product or changing the inputs and process used to manufacture a final product. The widely publicized assertions of the Monsanto Company—that it was unwilling to market calcium sodium metaphosphate, a substitute for asbestos as a reinforcing fiber and as a friction material, for fear of liability—must be viewed in the proper context.[112] First, there *is* evidence that the material might be carcinogenic,[113] and second, the substitute would be used by workers who had previous exposure to asbestos and who are at a much higher risk of developing cancer already. It is both logical and expected that Monsanto would not be willing to manufacture and market that product.[114] At the same time, it seems unreasonable to view Monsanto's withdrawal of this product as a "failure" of the liability system, if only because there would be no market for asbestos substitutes in the first place were it not for liability (and subsequently regulation).[115] Furthermore, tort liability for chronic disease should be expected to stimulate innovation of *significantly* safer products and discourage the development of products which may

112. See Mahoney and Littlejohn 1989, 1395. Even Vice President Quayle (1990, 1223) has alluded to the product as a victim of tort liability.

113. In fact, the Environmental Protection Agency concluded that the evidence obtained from Monsanto's two-year intrapleural implantation study in rats offered reasonable support for the conclusion that calcium sodium metaphosphate fibers can cause cancer. The agency argued that Monsanto was unable to refute "the low but essentially equal incidences of malignant pleural tumors observed in the calcium sodium metaphosphate and asbestos exposed rats but not in the concurrent control rats." U.S. Environmental Protection Agency 1986 (Status Report of August 19, 1986), 6.

114. While Monsanto may well believe that the product is safe (see U.S. Environmental Protection Agency 1986, submission dated May 15, 1986), the EPA does not, and the workers who are exposed to the new product might develop cancers indistinguishable from cancer caused by asbestos. That must be viewed as a unique situation in the context of product liability. Even if the product were to be used by an entirely different work force, it is not clear that the product would have been marketed when there was a serious disagreement between the regulatory agency and the marketing firm over the safety of the product.

115. Moreover, other Monsanto products, such as its herbicide Roundup, have enjoyed enormous market success. At least part of that success stems from the fact that some competitors' products, containing probable human carcinogens, have been withdrawn from the market, presumably because of liability risks.

present hazards that are only *slightly* less than the materials for which they might be substituted.[116] Thus innovation will be both enhanced and discouraged—and in precisely the socially desirable way—if there is adequate deterrence.

Conclusions and Policy Implications

In discussing acute chemical hazards, we concluded that the chemical firm's total liability costs represent no more than 70 percent of the corresponding social costs and that the liability system provides few-to-modest incentives to engage in preventive activities (see table 10-2). Then, addressing chronic chemical hazards, we noted that for signature diseases the chemical firm bears no more than 5 percent of the associated social costs and that the liability system creates some, but limited, deterrence; for non-signature diseases the chemical firm incurs liability costs of less than 0.1 percent of the associated social costs, and there is even less deterrence that would lead firms to develop safer products and processes. Insofar as positive deterrence exists, the present economic costs associated with liability can play a lesser or greater role. The concern of the firm to guard its reputation or to avoid punitive damages often plays a larger role, especially with regard to acute chemical hazards and signature diseases for which the firm may be clearly associated. That we have observed the development of both new products and processes when there is small or modest economic deterrence leads us to believe that increasing the economic costs associated with liability by more fully internalizing the social costs of chemical production would stimulate new technologies.

As we said in the beginning of the chapter, the effects of liability must be assessed in the context of other governmental interventions concerned with the safety of chemicals. When the inherent safety of a product or process is called into question, by a stringent regulation or ban or as a result of litigation, strong evidence exists that either the regulated firm or a new entrant will seize the opportunity to develop or adopt safer products or processes. Sometimes the regulated firm may simply abandon

116. A huge variety of asbestos substitutes already exist in the market (see, for example, Hodgson 1985). Monsanto's Phosphate Fiber (calcium sodium metaphosphate fiber) was expected to be "competitive" with other asbestos substitutes, but it was not a radical breakthrough with significant advantages over other asbestos substitutes already on the market. (Information obtained during a conversation on May 11, 1990, with James H. Senger, vice president, Environmental Policy, the Monsanto Company.)

the hazardous technology because it is unable to develop a safer substitute, while new entrants with different technological visions may be successful in developing a replacement.[117] An example from the regulatory arena is the development of a substitute transformer fluid by Dow-Silicone for Monsanto's PCBs.[118]

Since regulatory attention yields evidence that can be used in litigation, it is often difficult to apportion the source of the motivation for a firm's development of new technologies. Figure 10-5 shows the numbers of substances that have been designated as carcinogens. As the figure shows, many more substances might be candidates for regulation than have actually been regulated. But the mere fact that the substances have been signaled, tested, or studied epidemiologically makes them candidates for substitution. Conversely, for the many substances that have neither been targeted, tested, nor regulated, very little deterrence exists that might stimulate substitution. However, if the culture of the firm in its development of technology is changed by some examples of liability (perhaps falling on others), the firm may begin to develop safer products and processes across the board.[119] Changing attitudes of industry toward pollution prevention provides evidence of this cultural shift.

Uncertainty plays a large role in causing the firm to develop new technologies. Uncertainty about the possibility of regulation, once a substance has been designated a suspect hazard, drives many firms to develop substitutes so as not to be faced with a short time period in which they would be expected to respond. Uncertainty regarding the likelihood of tort action may likewise stimulate risk-averse firms, or firms guided by organizational routine rather than profit maximization (as discussed earlier), to search for or to develop substitutes.[120]

117. The same situation may arise when liability is the stimulus. Whatever characteristics of the chemical firm make it susceptible to litigation exposure in the first place are likely to impair its ability to develop safer products and processes in response. As a result, safety innovations frequently originate elsewhere in the market. This essential point is missed by those (such as Murray Mackay, in chapter 5 of this volume) who argue simplistically that the effectiveness of liability can be determined by observing whether those companies most exposed to litigation are the most innovative.

118. Ashford, Ayers, and Stone 1985, 432–33.

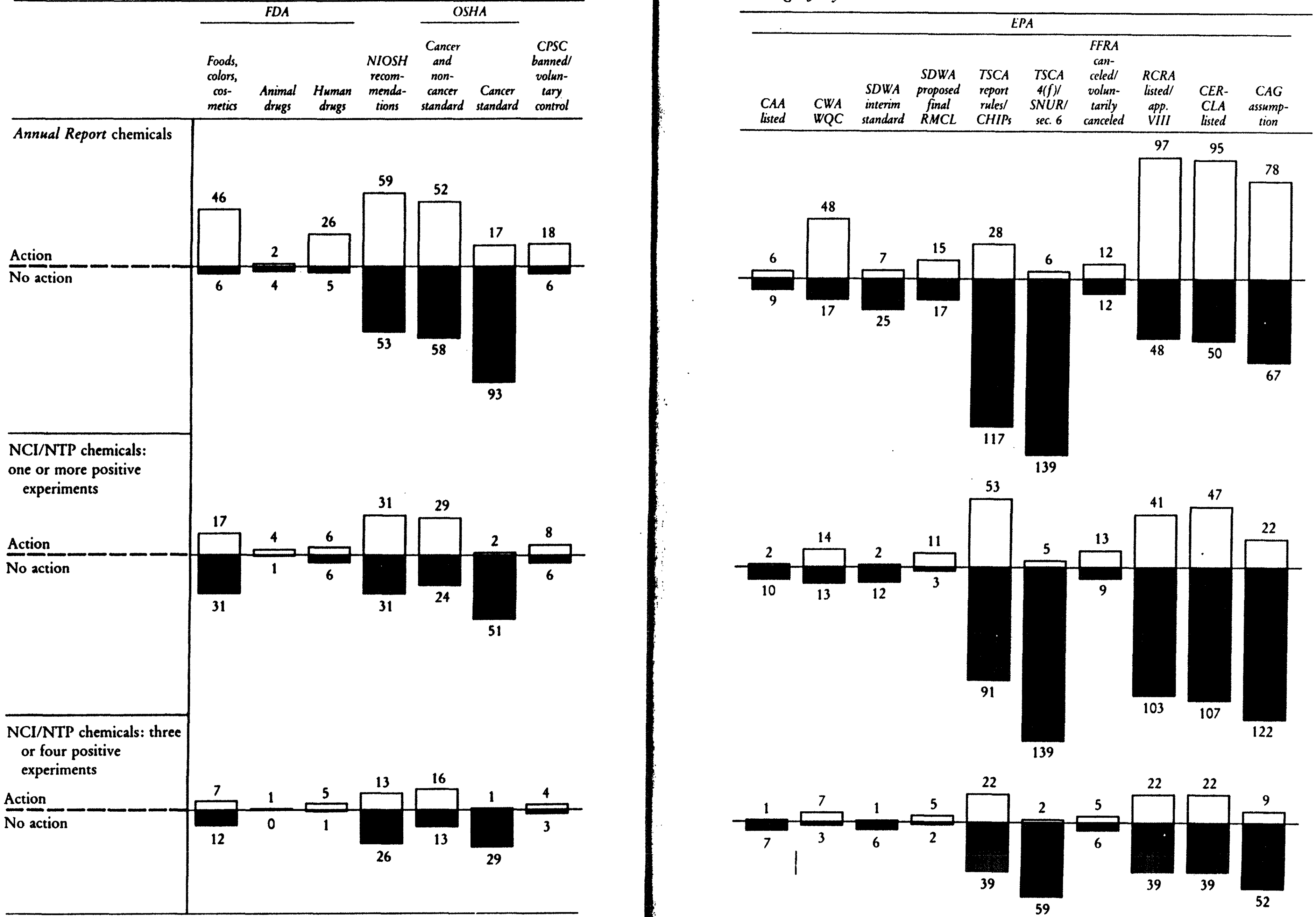
119. A survey of risk managers of 232 major U.S. corporations found that "where product liability has had a notable impact—where it has most significantly affected management decision making—has been in the quality of the products themselves. Managers say products have become safer, manufacturing procedures have been improved, and labels and use instructions have become more explicit." Weber 1987, 2.

120. Of course, too much uncertainty can have a paralyzing rather than a stimulative effect on the firm. For instance, truly unstable and unpredictable legal doctrine obviously undercuts the firm's ability to make optimal investments in safety. See, for example, Siliciano 1987. However, some uncertainty about having to pay for the damages it causes may stimulate the firm to undertake preventive action. By analogy, some randomness in income tax auditing has been shown to reduce taxpayer underreporting. See, for example, Scotchmer and Slemrod 1989.

Because of the gross underdeterrence in the context of chronic chemical hazards and the major underdeterrence in the context of acute chemical hazards, we suggest several changes in policy: an increased governmental role in developing and disseminating information about chemical hazards (beyond SARA title III and the OSHA hazard communication standard); increased regulation and economic charges for toxic and dangerous chemicals; increases in workers' compensation death benefits (particularly for scheduled diseases that are signature diseases or for diseases that clearly have a chemical etiology); and a limitation of access to bankruptcy protection that curtails the responsibility of the firm and removes any incentives to deal with the economic consequences of significant health hazards.

These observations and conclusions indicate that the recent demands for widespread tort reform, while directing attention to dissatisfaction with the tort system, tend to miss their mark, since significant underdeterrence in the system already exists. Thus proposals that damage awards be capped, that limitations be placed on pain and suffering and punitive damages, and that stricter evidence be required for recovery should be rejected. On the contrary, the revisions of the tort system should include relaxing the evidentiary requirements for recovery, shifting the basis of recovery to subclinical effects of chemicals, and establishing clear causes of action where evidence of exposure exists in the absence of manifest disease. Other tort remedies may also be entertained, but they must increase the amount of deterrence in the system, not further weaken the signals sent to the firm.

Figure 10-5. *Regulatory Actions on Potentially Carcinogenic Substances, through July 1987*[a]



Source: U.S. Office of Technology Assessment 1987, 20.

a. For each agency or program, OTA included only chemicals in the OTA-defined jurisdiction for that agency or program. Agency decisions that regulation is not necessary or appropriate were included in the no action groups. Because of overlap between the three lists of chemicals, it is not appropriate to add them together.

Key to acronyms: CAA—Clean Air Act; CAG—Carcinogen Assessment Group; CERCLA—Comprehensive Environmental Response, Compensation, and Liability Act; CHIPs—Chemical Hazard Information Profiles; CPSC—Consumer Product Safety Commission; EPA—Environmental Protection Agency; FDA—Food and Drug Administration; FIFRA—Federal Insecticide, Fungicide, and Rodenticide Act; NCI—National Cancer Institute; NIOSH—National Institute for Occupational Safety and Health; NTP—National Toxicology Program; OSHA—Occupational Safety and Health Administration; RCRA—Resource Conservation and Recovery Act; RMCL—recommended maximum contaminant level; SDWA—Safe Drinking Water Act; SNUR—Significant New Use Rule; TSCA—Toxic Substance Control Act; WQC—Water Quality Criteria.

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