Optimal Public Policies to Minimize Risks of Genotoxic Harms: A Comparison of the Efficiency of Administrative Agency Regulation & Tort Liability

Gary V. Johnson,
Thomas S. Ulen, &
Juha M. Alho

Food Marketing Policy Center
Research Report No. 1

Department of Agricultural Economics
& Rural Sociology
The University of Connecticut

Acknowledgements

This research was partially funded by The University of Connecticut Research Foundation and the University of Illinois Research Board. This paper was given on 4 October 1988 at the Symposium on Management of Risk from Genotoxic Substances in the Environment in Stockholm, Sweden.

Author Affiliation

Gary V. Johnson is an associate professor in residence at the Food Marketing Policy Center and the Department of Agricultural Economics and Rural Sociology, The University of Connecticut. Thomas S. Ulen is an associate professor at the Department of Economics and Institute for Government and Public Affairs, University of Illinois. Juha M. Alho is an assistant professor at the Institute for Environmental Studies and the Department of Statistics, University of Illinois.

Table of Contents

Abstract

Genotoxins, both radiation and chemical, by their nature have great capacity for creating unintended third-party harms (externalities), which are difficult to control from a policy standpoint. The difficulties presented by genotoxins stem from 1) the long latency between exposure and the resulting harm; 2) the potential that the size of the harm might be greater than the capitalized value of its generator (e.g., the Johns-Manville asbestosis cases in the U.S.A.); 3) the inability in many cases to determine the population exposed to the genotoxin and the extent of individual exposures. An additional difficulty that plagues environmental control policies in general, not just those targeted at genotoxins, is the inability to monitor without error. To be effective, policies to control genotoxins must deal with the uncertainty created by these difficulties in order to assure that risk generators (generators, users, and possibly disposers of genotoxins) take the proper level of precaution in their activities.

A model of the behavior of risk generators is created to analyze the economic efficiency of alternative policies for controlling external effects of genotoxin use under conditions of the uncertainty. The two broad policy categories examined are *ex ante* regulation (e.g., taxes, operational competency tests, and safety standards) and potential *ex post* exposure to financial liability for harms. A stochastic simulation of this behavioral model was then undertaken. This analysis gives rise to several unique findings. First, that due to uncertainty an economically efficient level of precaution in the use of genotoxins will not be taken by risk generators when only *ex post* policy of strict liability is employed. This finding holds for the case of probabilistic causation as well. Second, that if either *ex post* strict liability with punitive damages or *ex post* strict liability with an uncertain *ex ante* regulation is used the minimum of the firm's costs will occur at the social optimum, but the firm's loss function will have nonconvexities. Third, given simultaneous use of *ex post* strict liability with the appropriate level of punitive damages and an appropriate uncertain *ex ante* regulation the global minimum of the firm's costs will occur at the social optimum. Fourth, the use of *ex ante* regulation with *ex post* liability results in marked nonconvexities at low levels of precaution. This finding may point to the desirability of using punitive damages as a corrective to strict liability.

1. Introduction

Both radiation and chemical genotoxins by their nature have great capacity for creating unintended third-party harms (externalities), which are difficult to control from a policy standpoint. The difficulties stem from 1) the long latency between exposure and the resulting harm; 2) the potential that the size of the harm might be greater than the capitalized value of its generator (e.g., the Johns-Manville asbestosis cases in the USA); 3) the inability in many cases to determine the population exposed to the genotoxin and the extent of individual exposures. An additional difficulty that plagues environmental control policies in general, not just those targeted at genotoxins, is the inability to monitor without error.

In the USA two types of policy are used to control harms from genotoxins—administrative agency regulation (*ex ante* regulation) and tort liability (*ex post* regulation). The premise with *ex ante* regulation is that potential generators of genotoxic harms are constrained in the generation of these harms by safety standards, operational competency tests, taxes, etc. *Ex post* regulation, on the other hand, limits exposure to genotoxins by making generators of those harms liable in private causes of action for compensating those whom they have harmed. In this latter type of regulation it is this expectation of liability that constrains the generators of the harms. Except where specifically limited or relieved by legislation (e.g., nuclear power plant accidents in the USA), generators always are liable for third-party harms and face *ex post* regulation. Only when specifically legislated do generators face *ex ante* regulation.

This article attempts to analyze these two types of regulation in their relative efficiency to overcome the above difficulties associated with the control of genotoxic harms from an economic perspective. The question naturally arises whether *ex ante* regulation and *ex post* regulation are complements or substitutes. Economic intuition would suggest that they are substitutes; either alone would seem to be able to accomplish the goal of creating efficient incentives, but to use them jointly would seem to be wasteful duplication. However, this intuition is always correct only when there is no uncertainty in the enforcement of either the administrative agency standard or the tort liability standard. In that unlikely case, the two methods of regulation are, indeed, substi-

1. Introduction

Both radiation and chemical genotoxins by their nature have great capacity for creating unintended third-party harms (externalities), which are difficult to control from a policy standpoint. The difficulties stem from 1) the long latency between exposure and the resulting harm; 2) the potential that the size of the harm might be greater than the capitalized value of its generator (e.g., the Johns-Manville asbestosis cases in the USA); 3) the inability in many cases to determine the population exposed to the genotoxin and the extent of individual exposures. An additional difficulty that plagues environmental control policies in general, not just those targeted at genotoxins, is the inability to monitor without error.

In the USA two types of policy are used to control harms from genotoxins—administrative agency regulation (*ex ante* regulation) and tort liability (*ex post* regulation). The premise with *ex ante* regulation is that potential generators of genotoxic harms are constrained in the generation of these harms by safety standards, operational competency tests, taxes, etc. *Ex post* regulation, on the other hand, limits exposure to genotoxins by making generators of those harms liable in private causes of action for compensating those whom they have harmed. In this latter type of regulation it is this expectation of liability that constrains the generators of the harms. Except where specifically limited or relieved by legislation (e.g., nuclear power plant accidents in the USA), generators always are liable for third-party harms and face *ex post* regulation. Only when specifically legislated do generators face *ex ante* regulation.

This article attempts to analyze these two types of regulation in their relative efficiency to overcome the above difficulties associated with the control of genotoxic harms from an economic perspective. The question naturally arises whether *ex ante* regulation and *ex post* regulation are complements or substitutes. Economic intuition would suggest that they are substitutes; either alone would seem to be able to accomplish the goal of creating efficient incentives, but to use them jointly would seem to be wasteful duplication. However, this intuition is always correct only when there is no uncertainty in the enforcement of either the administrative agency standard or the tort liability standard. In that unlikely case, the two methods of regulation are, indeed, substitutes, and social costs of regulating the externality are minimized by sole use of whichever of the two forms of regulation has the lower administration and enforcement costs. A more likely case is that there is uncertainty in the enforcement of either or both forms of regulation. Where that is true, then *ex ante* regulation and *ex post* regulation may become complementary regulatory tools. We have recently shown that the joint use of these forms of regulation creates efficient incentives for potential externality-generators when uncertainty regarding the enforcement of the *ex post* liability rule causes firms to take less precaution to prevent harms than is socially optimal and when there is certainty regarding the enforcement of the *ex ante* regulatory standard (Kolstad, Johnson, and Ulen; 1986). These results have been extended to include uncertain enforcement of *ex ante* regulation in another recent paper (Johnson and Ulen; 1988). In this article we test these propositions in a simulation model for the case of genotoxic harms.

In the following section of the paper we summarize the economic analysis of tort liability standards (*ex post* regulation). Succeeding sections discuss a theoretical model of uncertainty in *ex ante* and *ex post* regulation, identify the hypotheses suggested by that model, and explain the stochastic model we test and report on the results from that model. A concluding section summarizes the policy implications of our results.

2. The Economics of Tort Liability

The simple economic premise underlying tort liability is that the potential injurer (and victim) will be induced to take optimal precaution against harm if he is liable for compensating those whom he harms. This potential liability becomes a part of the decision maker's anticipated costs, which he then attempts to minimize by taking the optimal amount of precaution. The common law recognizes two different tort liability standards—negligence and strict liability. In the case of genotoxic harms strict liability is generally the standard that is applied. The economic analysis of tort liability *has* provided an explanation for when this standard is efficient (see, Cooter and Ulen; 1988). Let us briefly summarize this explanation.

2.1 Strict Liability

Under a strict liability standard an injurer is liable for the victim's losses if he proximately caused the harm. The potential injurer is under an absolute duty not to cause harm; there is no legal standard of care or precaution that he may take to exonerate him from liability for the victim's losses, although there are legal defenses open to him. Moreover, there is usually no requirement that the potential victim himself take care; the entire burden is on the potential injurer. Strict liability creates efficient incentives for precaution by the potential injurer under three conditions:

1. when he or she is liable to the victim for "perfect" compensation,

2. when precaution is "unilateral," and

3. when there is no uncertainty in the enforcement of the strict liability standard.

Perfect compensation is an award of monetary damages to the victim that makes him indifferent between the state of having suffered the harm but receiving the monetary damages and that of never having suffered the harm. Precaution is said to be unilateral when only the potential injurer may reasonably be expected to take action to reduce the probability or severity of harm.

Uncertain enforcement can arise under strict liability in two ways. First, the determination of proximate cause may be subject to uncertainty: an injurer may be held strictly liable when in fact his actions did *not* proximately cause harm or he may be excused from liability when in fact his actions *did* proximately cause the injury. Second, the victim's compensation can be imperfectly measured: some victims whose loss was minimal may be vastly overcompensated while others whose loss was extraordinarily large may be undercompensated. Where there is uncertain enforcement in either or both of these senses, the efficiency of strict liability is lessened.

2.2 Correctives for Uncertainty in *Ex Post* Liability

The uncertain enforceability of a strict liability standard clearly lessens its efficiency. The question that this lessened efficiency raises is whether there is some way to improve the efficiency of an uncertainly-enforced *ex post* regulatory rule. There are several possibilities:

1. if uncertainty leads to too much or too little precaution, the rules for establishing fault or causation could be relaxed or tightened;

2. assuming that potential injurers take too little precaution, courts could routinely award punitive damages in addition to compensatory damages in those instances where an injurer is held liable;

3. some alternative policy tool for minimizing the external harm might be substituted, e.g., the activity could simply be outlawed or victims could be compensated in an administered-compensation or no-fault system; or

4. a complementary *ex ante* regulatory tool could be used.

2.3 The Interaction of Tort Liability and Statutory Regulation: The Case of Environmental Harms

To focus the discussion, let us apply the foregoing analysis to a concrete problem in environmental regulation: harms arising from exposure to hazardous wastes.[1] Let us first briefly summarize the federal and state statutory regulations dealing with that problem and then discuss how the economic analysis of tort liability might be applied to this issue.

In 1976 Congress passed the Resource Conservation and Recovery Act of 1976 (RCRA).[2] That act provided for tracking hazardous wastes from the time and point of generation until final disposal but failed to provide for any problems associated with improper disposal before 1976. In 1980 Congress attempted to correct this failure in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).[3] That act empowered the Federal government through the EPA to impose liability for cleaning up hazardous waste disposal sites closed before the enactment of RCRA. CERCLA has been revised, but its basic structure remains intact.

State statutory regulation is predictably less coherent. Some states have "mini-superfunds," and many have additional, more direct controls. For example, Illinois and Massachusetts have banned landfilling, the most popular and economical method of disposing of hazardous wastes; some states have extended the reporting requirements of RCRA to small firms, such as dry cleaners and gasoline stations, that are exempt from the federal regulations.

The common law tort liability treatment of harms arising from the generation and disposal of hazardous wastes is in its infancy. Only a handful of actions has been filed, so it is not clear how the common law will treat these matters. For that reason we may begin at the beginning and explore how the common law *should* deal with hazardous wastes by applying the economic analysis of tort liability sketched above. For the harms created by the generation, transportation, and disposal of hazardous wastes, precaution is certainly unilateral in the sense that disposers and generators are the only parties to whom society may reasonably look for actions that will reduce the probability or severity of harm from those sources. Thus, if this harm is to be regulated using an *ex post* liability rule, injurers should be held strictly liability to those they have harmed.

But what about the problems of uncertain enforcement under strict liability? Recall that in making a claim for recovery under strict liability, the victim must show that the injurer proximately caused the harm. Two problems are likely to arise in establishing that the generation or disposal of hazardous waste has proximately caused a harm. First, the scientific evidence on causation between exposure to these substances and personal or property injury is at an early stage of development. Thus, by the standards of the academic community the causal connection may be reasonably well established, but by the standards of proof required in a court the causal connection is not clear enough to permit perfect compensation. Second, harms arising from the generation or disposal of hazardous wastes may not become manifest for long periods of time, sometimes more than a generation. If so, the evidence necessary to establish proximate cause for recovery under a strict liability theory may be so distant or so clouded that otherwise meritorious plaintiffs cannot recover. Where this is the case, then the generators and disposers of hazardous wastes do not receive the appropriate signal from the tort liability system about setting the level of precaution to be taken, and as a consequence they may take too little precaution.

To what extent can the strict liability standard be amended to take account of the above special problems? With regard to the problem of establishing proximate cause where scientific evidence is weak, there are several possibilities. Legislation might relax the plaintiff's burden of proof on the causation issue, as was the case in the 1983 Minnesota Environmental Response and Liability Act (MERLA), and has been proposed by some commentators for widespread adoption in other cases like those for genotoxic harms.

This relaxation of the plaintiff's burden of proof on the causation issue from harms arising from the generation of disposal of hazardous and toxic wastes may cure the first problem noted above, but it does so at a high cost. Tampering with the traditional causation standard is a radical step that requires extraordinary justification, a justification that no one has offered. Naturally the question arises: if the inadequacy of scientific knowledge to establish proximate cause in the case of harms arising from hazardous and toxic wastes justifies relaxing the plaintiff's burden of proof, why may we not also relax plaintiffs' burdens in all other instances of inadequate scientific knowledge? Without a good answer to this question, relaxation of the plaintiff's causation requirement is not yet an acceptable method of making strict liability for harms inflicted by exposure to hazardous and toxic wastes more efficient.

The second source of uncertain enforcement of strict liability for harms associated with hazardous wastes is the long time lag between exposure and manifestation of the harm. This lag complicated the victim's ability to demonstrate proximate cause and, therefore, makes his recovery less likely, even if his case is meritorious. This problem has arisen in several well-known modern cases, e.g., in the diethylstilbestrol (DES) and asbestos cases. Some commentators have suggested that the tort liability system can be reformed to accommodate the peculiar evidentiary problems of time-delayed harms by allowing probable victims to recover from a probable injurer before any actual harm has become manifest. The proposal is that where the probability of any harms developing in the future is above some minimum threshold, the potential victims should be allowed to recover the expected damages discounted by the probability that the harm will arise (Cooter and Ulen; 1988).

It is argued that the benefit of allowing recovery under a theory of probabilistic causation for inflicting tortious risk is that the signal to take efficient precaution will be transmitted relatively quickly to potential injurers. Not allowing recovery in these circumstances, it is argued, will greatly reduce the number of cases that plaintiffs can win in the distant future and consequently will greatly dilute the signal to injurers to take efficient precaution. But the costs of revamping tort law to allow for probabilistic causation and recovery for infliction of tortious risk are also high. One of the most fundamental precepts of tort law is that a harm must have occurred; simply creating a dangerous condition—what has been called, in a famous phrase, "negligence in the air"—is not a sufficient basis for bringing an action. There are good efficiency reasons for limiting recovery in tort to cases of actual harm. Moreover, there are almost insurmountable problems involved in specifying the threshold probability of harms that would trigger liability.

Finally, the last remedy for modifying *ex post* liability in the face of uncertainty is to allow plaintiffs to collect punitive damages. Punitive damages allow compensation of the injured party at a higher rate than perfect compensation. This rate of compensation is typically some multiple of the perfect compensation rate. At first this policy appears to violate the economic efficiency criteria for strict liability. However, with the introduction of uncertainty this may not be the case.

These observations suggest that the uncertain enforcement that is likely to arise under a strict liability standard for harms arising from exposure to hazardous wastes may not be easily corrected with the *ex post* regulation system itself. It is still an open question whether an uncertainly-enforced tort liability standard is best supplemented or replaced by uncertainly-enforced federal and state *ex ante* administrative agency regulation. We turn to that question in the next section, where we summarize a formal model of firm behavior under uncertainly-enforced *ex ante* and *ex post* regulation.

3. A Stochastic Model of Regulation

3.1 Definitions and Assumptions

We shall define a stochastic model that represents a firm that has to decide on a level of precaution to adopt to prevent possible genotoxic harms its production processes may cause. Random variables will represent the (subjective) uncertainty the firm has concerning the amount of harm likely to be caused at any level of precaution whether or not it will be brought to court and found liable, and whether or not it will be found in violation of a possible regulatory standard. The firm is assumed to choose its level of precaution to minimize its expected loss. Regulatory systems combining *ex post* regulation with punitive damages, and *ex ante* regulations based on standards with fixed fines for noncompliance are considered.

Consider a firm which takes $x \geq 0$ units of precaution to prevent harms. Suppose the exact cost of precaution is known to the firm. Then, we can let the variable $C(x) \geq 0$ represent the actual cost. We shall assume that $C(x)$ is an increasing *strictly convex* function of x, i.e., $C'(x) > 0$ and $C''(x) > -(C'(x))^2$. We shall also assume that $C(x) \to -\infty$ as $x \to 0$ and $C(x) \to +\infty$ as $x \to +\infty$.

The actual harms caused at the level of precaution are given by a random variable $H(x) \geq 0$, such that $K(x) = \log H(x)$ satisfies

$$K(x) \sim N[k(x) - \sigma_k^2/2, \sigma_k^2], \sigma_k \geq 0. \qquad (1)$$

Consequently, $E[H(x)] = \exp(k(x))$ for all σ_k. The expected harms are assumed to be a *decreasing-convex function* of x. Or, we take $k'(x) < 0$, and $k''(x) \geq -(k'(x))^2$. Furthermore, we require that $k(0)$ is finite and $k(x) \to -\infty$ as $x \to +\infty$.

These concepts allow us to define the socially optimal level of precaution x . Suppose the firm would suffer, itself, all the harms it causes. Then, it would face a random loss

$$L(x) = C(x) + H(x), \qquad (2)$$

which has the expectation $l(x) = E[L(x)] = C(x) + \exp(k(x))$. By our assumptions, $l(x)$ has a unique minimum for some $x^* \geq 0$. This is called the *socially optimal level of precaution.* If

the (right) derivative of the expected loss function at zero is $l'(0) < 0$, then the unique minimum $x = x^*$ is the only point satisfying $l'(x) = 0$. The unique minimum expected loss will occur at that x (x^*) where the marginal cost of precaution equals the negative marginal expected harms. Even in the case of strict liability, x^* is the level of precaution that society would like to see the firm employ (see Johnson and Ulen, 1986).

In reality, the firm inflicts harms on outsiders. The problem we would like to address is then: Is there a way the regulatory system (*ex post* and possibly *ex ante* regulation) can induce the firm to adopt the socially optimal level of precaution? A simple solution to this would be to make the firm always pay for all the harms it causes.[4] In practice, this solution is not feasible. Tort liability requires that the person harmed bring a case to court. This typically depends on the magnitude of the harm caused. The court's decision on liability depends, in turn, on how it views the level of precaution taken by the firm. If a regulatory agency exists, it will also judge the level of precaution taken by the firm and apply a possible fine.

We shall assume that there is a simple threshold such that a case against the firm comes to court, if and only if the harms exceed $\exp(k_0)$, or $K(x) > k_0$. Additional determinants, such as the likelihood of winning the case, could also be introduced. However, they would unnecessarily complicate the model by involving considerations relating to the level of precaution rather than to the level of damages. The former will be present in the model through the following assumptions.

Once a case against the company comes to court, the court shall form an opinion of the level of precaution x. The firm's perception of this uncertain guess is modeled in terms of a random variable $\exp(Y_1(x))$, where

$$Y_1(x) \sim N(\log x - \sigma_1^2/2, \sigma_1^2), \sigma_1 \geq 0, \qquad (3)$$

given the court's guess $Y_1(x)$, the firm will be found liable, if and only if $Y_1(x) < y_1$, where y_1 is a threshold level. Note that under this assumption $E[\exp(Y_1(x))] = x$, i.e., the court is assumed to be unbiased.

When found liable, a firm is currently made to compensate the amount of harm it caused, or pay $H(x) = \exp(K(x))$.

We shall generalize the model to include "punitive damages" (rewards!) in terms of a multiplicative factor $\exp(d_0)$. In other words, when found liable, the firm's expected payment is $\exp(K(x) + d_0)$.

We may also have a regulatory agency supervising compliance to a possible standard of precaution. The firm's perception of the agency's uncertain guess about x is represented by a random variable $\exp(Y_2(x))$, where

$$Y_2(x) \sim N[\log(x) - \sigma_2^2/2, \sigma_2^2], \sigma_2 \geq 0. \tag{4}$$

The firm is found to be in violation of the standard, if and only if $Y_2(x) < y_2$, where $\exp(y_2)$ is the lowest acceptable level of precaution. When found in violation, the firm must pay a fine of $\exp(f_0)$. Taking $y_2 = \infty$ $(f_0 = -\infty)$ represents the case of no regulatory agency.

To complete our model, we shall assume that K(x) is independent of $Y_1(x)$ and $Y_2(x)$, and of each other.

Altogether, our model has six parameters: k_0, σ_k, y_1, σ_1, y_2, and σ_2. They determine the likely cost of precaution, the probability that the firm is brought to court and found liable, and the probability that it will have to pay a fine. Despite the many simplifications mentioned above, the model appears to be sufficiently rich to allow a realistic description of many types of regulatory circumstances met in practice.

3.2 Expected Loss Function

Under our assumptions the firm's loss function is random. It is a sum of C(x), and of $\exp(K(x) + d_0)$ if brought to court and found liable, and of $\exp(f_0)$ if found in violation of a regulatory standard. We can use indicator functions to write this more precisely.

The *indicator function of event* A is

$$1_A = \begin{cases} 1, & \text{if A occurs,} \\ 0, & \text{otherwise.} \end{cases} \tag{5}$$

For example, take $A = \{K(x) > k_0\}$. Then $1_A = 1$ means that a case comes to court, and $1_A = 0$ means that it doesn't. Similarly $1_{\{K(x) > k_0\}} 1_{\{Y_1(x) < y_1\}} = 1$, if and only if a case comes

to court and the firm is found liable. Using this notation, we can write the firm's random loss function $L_1(x)$ as

$$L_1(x) = C(x) + 1_{\{K(x) > k_0\}} 1_{\{Y_1(x) < y_1\}} \exp(k(x) + d_0) + 1_{\{Y_2(x) < y_2\}} \exp(f_0). \tag{6}$$

The firm's *expected loss function* $l_1(x) = E[L_1(x)]$ becomes

$$l_1(x) = C(x) + h_1(x) + h_2(x), \tag{7}$$

where

$$h_1(x) = \exp[d_0 + k(x)] \, \Phi(Z_1)[1 - \Phi(Z_k)], \tag{8}$$

$$h_2(x) = \exp(f_0) \, \Phi(Z_2), \tag{9}$$

$$Z_1 = \frac{y_1 - [\log(x) - \sigma_1^2/2]}{\sigma_1} \tag{10}$$

$$Z_k = \frac{k_0 - [k(x) + \sigma_k^2/2]}{\sigma_k} \tag{11}$$

$$Z_2 = \frac{y_2 - [\log(x) - \sigma_2^2/2]}{\sigma_2} \tag{12}$$

and

$$\Phi(x) = (2\pi)^{-1/2} \int_{-\infty}^{t} \exp(-s^2/2) \, ds. \tag{13}$$

Although somewhat complicated, the above formula for $l_1(x)$ is useful because we can directly read some properties of the model from it. Note that *the function $l_1(x)$ can easily fail to be convex*. Perhaps the simplest way to see this is to take, $k_0 = +\infty$. Then $h_1(x) = 0$ and $h_2(x)$ is proportional to one minus the standard normal distribution function. Letting σ_2 approach zero, $h_2(x)$ approaches a step function which jumps down from $\exp(f_0)$ to zero and y_2. Obviously the sum of $h_2(x)$ and C(x) can then be non-convex. The same can occur when only $h_1(x)$ is present, or when both $h_1(x)$ and $h_2(x)$ are present as long as the parameters have been chosen appropriately. One implication of this is that any solution of $l_1(x) = 0$ is not automatically a global minimum.

We shall now present some simple examples of how to determine candidates for optimal values of d_0 and f_0, in order that the firm would find it advantageous to decide to take the socially optimal level of precaution x^*.

Example: no regulatory agency ($y_2 = -\infty$) and no punitive damages ($d_0 = 0$). In this case there is only *ex post* liability. Earlier work (Kolstad, Johnson, and Ulen; and Johnson and Ulen) indicates that under these circumstances $l_1'(x^*) \neq 0$ and the loss function may not be strictly convex.

Example: no regulatory agency ($y_2 = -\infty$), no punitive damages ($d_0 = 0$), and $\Phi(Z_k) = 1$ for $k(x) \leq k_0$ otherwise 0, i.e., the probability approaches a step function.[5] This is the case of probabilistic causation. Again the earlier work (Kolstad, Johnson, and Ulen; and Johnson and Ulen) would indicates that under these circumstances $l_1'(x^*)$ will become undefined and the loss function may not be strictly convex.

Example: no regulatory agency ($y_2 = -\infty$). In this case $l_1'(x^*) = 0$ implies that we must take $d_0 = d^*$. d^* is a function of y_1, σ_1, k_0, and σ_k and is given by

$$d^* = \log\left\{\frac{k'(x^*)\exp[k(x^*)]}{g_1(x^*)}\right\}. \quad (14)$$

where $g_1(x) = \exp(-d_0)h_1'(x)$.[6] We will see in the next section that d^* may not result in a strictly convex expected loss function for the firm, holding out the possibility of local rather than global optima.

Example: constant relative damages and a fixed fine ($f_0 > 0$). The optimal fine is given by

$$f_0 = \log\left\{\frac{k'(x^*)\exp[k(x^*)] - g_1(x^*)\exp(d_0)}{g_2(x)}\right\} \quad (15)$$

where $g_2(x) = \exp(-f_0)h_2'(x)$. There is a one-to-one function between d_0 and f_0. For $d_0 = d^*$, d^* is the value corresponding to $f_0 = -\infty$, i.e., no regulatory agency, and for $f_0 = f^*$, f^* is the value corresponding to $d_0 = 0$, i.e., no punitive damages. Even though the courts and the regulatory agency appear, in this case, to be substitutes, we shall see in the next section that in many cases a suitable choice of $d_0 < d^*$ and the corresponding f_0 will yield a *global* minimum at x^* rather than a *local* one.

In the next section we operationalize the above stochastic model and examine the above examples with the resulting model.

4. Simulation of the Stochastic Model

4.1 Parameter Values

In order to operationalize the above model we need to choose values of the parameters k_0, σ_k, y_1, σ_1, y_2, and σ_2. We will also need to define the functions $C(x)$ and $k(x)$. Let us first define the latter two functions. The firm's cost of precaution will be given by

$$C(x) = 37.9x^{2.1}$$

where x can range from 1 to 100 units. While the choice of this cost function is arbitrary, it is a member of a class of functions commonly used by economists in statistical estimation of cost data for operating firms. The function meets the assumption of strict convexity required by the stochastic model. The function $k(x)$ for the firm is given by

$$k(x) = 13.8155 - 0.046x.$$

Given this function the firm's expected loss is given by

$$l_1(x) = 37.9x^{2.1} + \exp(13.8155 - 0.046x).$$

Figure 1 shows the social cost function (Equation 2) for this formulation of the firm's loss function, which has a unique minimum at $x^* = 46.458$ units of precaution.

The stochastic model developed in the previous section has the characteristic that all the σ_is, (i = k, 1, 2) can be thought of as percentage variations from the appropriate mean values. a σ_k of .025 would represent a 2.5% deviation from the expected harm function for the firm. Given this knowledge, we are now ready to choose appropriate values for the six parameters in the model. As stated earlier in the paper, cases of tort liability involving genotoxic harms have several characteristics. First characteristic is that there is a great deal of uncertainty on the part of the firm regarding the magnitude of the harms and that cases are only brought to court when substantial monetary harms have occurred. A $k_0 = 12.20967$ will be chosen to reflect this fact, which is 5% larger than $k(x^*)$. This equivalent to a monetary harm of $200,720. Furthermore, σ_k will be set at 0.25 reflecting a large but not too large level of uncertainty associated with harms.

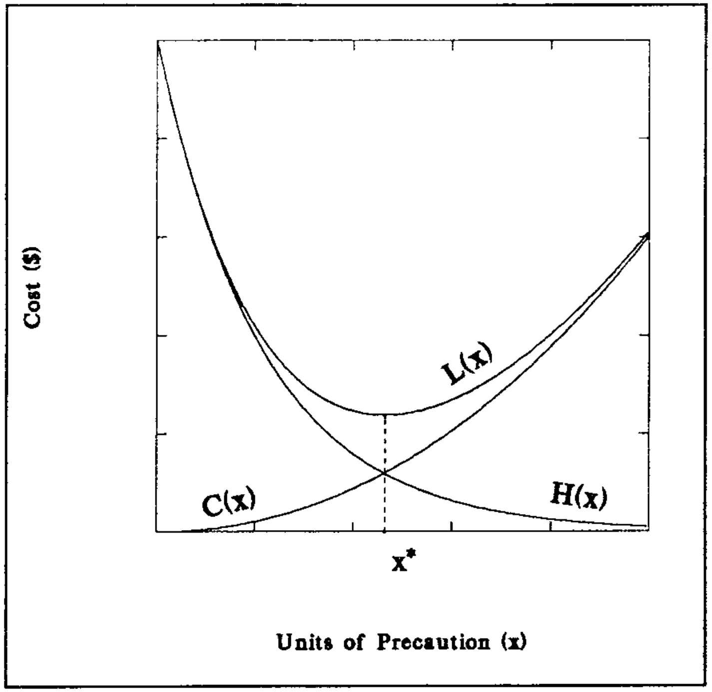

Figure 1. THE SOCIAL COST FUNCTION.

The second characteristic is that strict liability is the tort liability standard. Johnson and Ulen (1988) have shown that this can be represented by requiring that the level of precaution demanded by the court be greater than x^*. In the present setting this is accomplished by setting $y_1 = 4.057$, which is an x of 57.8186. The third characteristic is related to the second and reflects the difficulty of the court in determining proximate cause. This is reflected in the model by allowing σ_1 to equal 0.25.

There is no apriori information to determine the appropriate level of y_2 and σ_2, however earlier theoretical literature (Kolstad, Johnson, and Ulen) indicates that $\exp(y_2)$ should be less than x^*. We will allow y_2 to vary between 3.557 and 4.057 and σ_2 to vary between 0.05 and 0.25. Given these parameter values and explicit functions let us now turn to the case of tort liability with punitive damages and *no ex ante* regulation.

4.2 No *Ex Ante* Regulation

4.2.1 Strict Liability

This is the case of the absence of both a regulatory agency ($y_2 = 0$) and punitive damages ($d_0 = 0$). As can be seen in Figure 2, this results in the minimum of the firm's loss function occurring at $\hat{x} < x^*$. Thus liability alone leads to underprecaution in the case of genotoxic harms. This result agrees with those from earlier work (Kolstad, Johnson, and Ulen; Johnson and Ulen). Note also the nonconvexity of the loss function. This nonconvexiety is important because it points to the potential of local and possibly global optimums other than x^*.

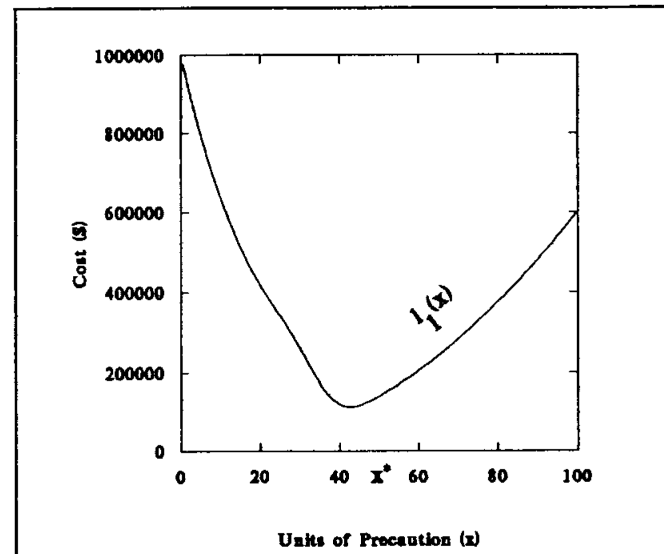

Figure 2. THE FIRM'S LOSS FUNCTION UNDER STRICT LIABILITY.

4.2.2 Strict Liability with Probabilistic Causation

This is the case given in the second example in Section 3.2. As can be seen in Figure 3 the minimum of the firm's cost function occurs at a level of precaution even further from x^* than in the previous case. In this policy formulation the location of the global minimum is crucially dependant on the choice of k_0. The larger k_0 is the closer this minimum will occur to the origin. This gives us an additional argument for rejecting probabilistic causation as a correction to an uncertain strict liability standard.

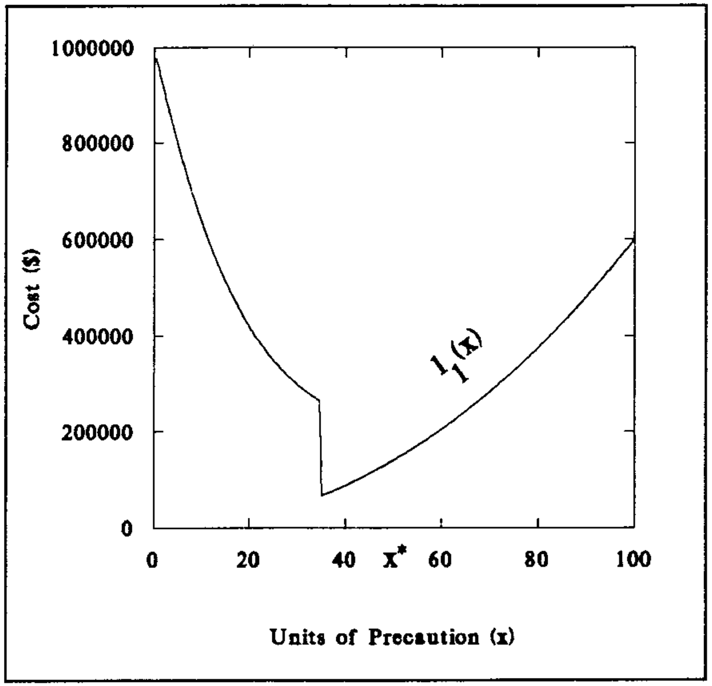

Figure 3. STRICT LIABILITY WITH PROBABILISTIC CAUSATION.

4.2.3 Strict Liability with Punitive Damages

As stated in the example in section 3.2 the case of punitive damages with no regulatory agency present is characterized by $y_2 = -\infty$. We can make d^* under these assumptions a function of σ_1 and study its behavior. If for large (small) values of σ_1, d^* is positive it indicates that when uncertainty is large (small) firms will take too little (much) precaution. This can be seen in Figure 4 where the upper curve is for a large k_0, and the middle and lower curves are for successively smaller k_0's (all k_0's are larger than $k(x^*)$). Note that for k_0 small in the figure that $\exp(d^*) < 1$, therefore $d^* < 0$ and the firm pays less than full compensation. The effect of using punitive damages is seen in Figure 5. The global

optimum is moved to the social optimum x^*. Note, however, that the resulting loss function is nonconvex.

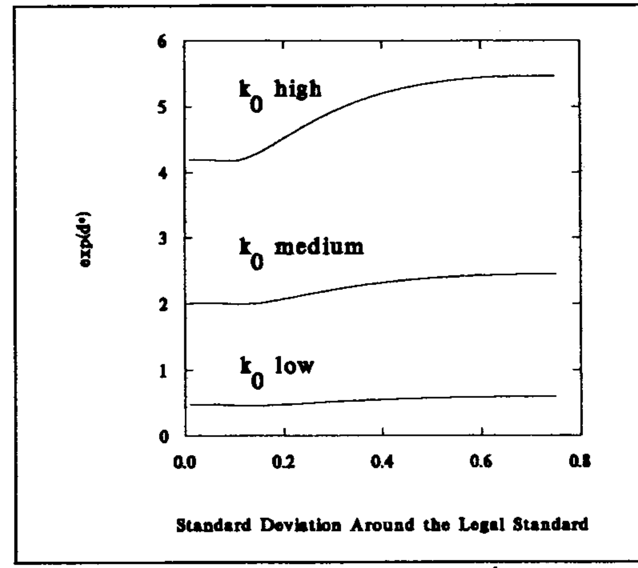

Figure 4. THE RELATIONSHIP BETWEEN D^* AND σ_1.

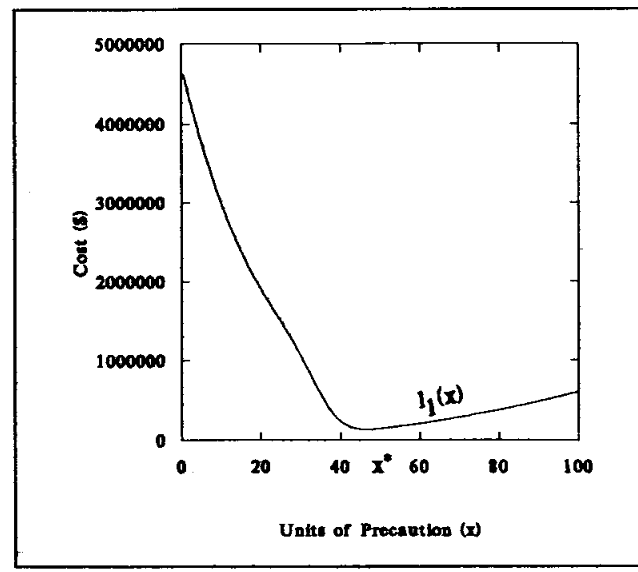

Figure 5. THE STRICT LIABILITY WITH PUNITIVE DAMAGES, $D_0 = D^*$.

4.3 *Ex Post* and *Ex Ante* Regulation

In studying the joint use of these regulatory regimes let us first look at the use of *ex post* liability without punitive damages but with *ex ante* regulation. Using Equation 15 an $f_0 = f^*$ can be calculated for $d_0 = 0$. The impact of using *ex ante* regulation can be seen in Figure 6. The startling non-convexeiety at low levels of x is disconcerting However, the remainder of the curve is well behaved and even with the nonconvexeiety the global optimum is at x^* From the sensitivity analysis on y_2 and σ_2, it was determined that there appears to be a tradeoff between where y_2 is set and the size of σ_2.

The impact of using *ex ante* regulation with *ex post* regulation without punitive damages is the similar to that of using *ex post* regulation alone with d_0 set equal to d^* as shown in Figure 5. The main difference between these results and those in Figure 7 is the nonconvexeiety at small levels of x. This result is much less startling than that in Figure 6. The values of the parameters in Figure 7 are $d_0 < d^*$; σ_k, σ_1, and σ_2 are set at 0.25; k_0 and y_1 are high, i.e., $k_0 > k(x^*)$, $\exp(y_1) > x^*$; and y_2 is small, i.e., $\exp(y_2) < x^*$. As we can see that given this case *ex post* and *ex ante* regulations can once more be viewed as compliments.

5. Conclusions

There are two groups of conclusions that can be drawn from the formal model. The first group of conclusions regards the use of just *ex post* strict liability rule by itself when there is uncertain enforcement. The second group of conclusions concerns the complementary use of *ex ante* regulation with *ex post* strict liability.

5.1 *Ex Post* Strict Liability

The conclusions regarding the sole use of *ex post* strict liability to control harms from environmental genotoxins are:

- if strict liability is used with or without probabilistic causation and without punitive damages then the minimum of the firm's loss function will be less than the social optimum; and

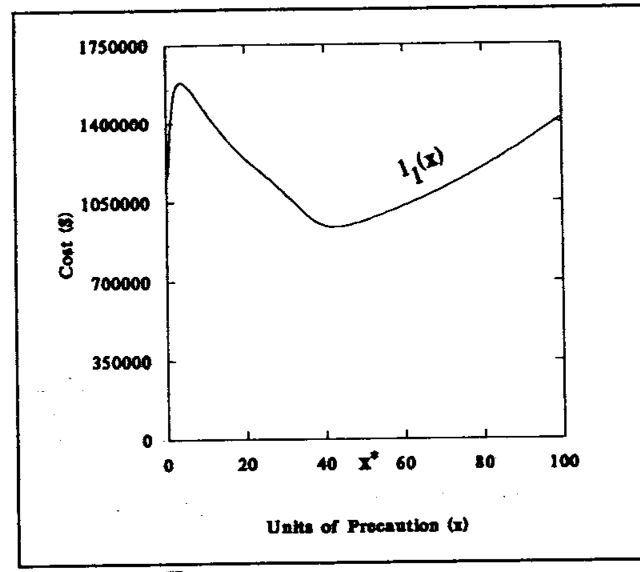

Figure 6. THE USE OF STRICT LIABILITY WITHOUT PUNITIVE DAMAGES AND *EX ANTE* REGULATION.

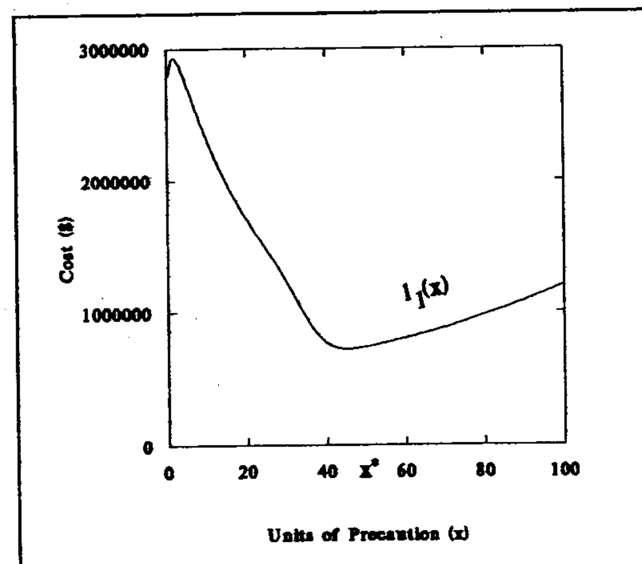

Figure 7. THE JOINT USE OF STRICT LIABILITY WITH PUNITIVE DAMAGES AND *EX ANTE* REGULATIONS.

- if strict liability is used with punitive damages then the firm's loss function will have a minimum at the socially optimal level of x but the loss function is nonconvex and the minimum potentially may not be the global minimum for the function.

5.2 Joint Use of *Ex Ante* Regulation and *Ex Post* Strict Liability

The conclusions that can be drawn regarding the complimentary use of *ex ante* regulation and *ex post* strict liability are:

- that *ex post* strict liability with punitive damages is a substitute for the joint use of *ex ante* regulation and *ex post* strict liability without punitive damages;

- that there is a tradeoff between the uncertainty surrounding an *ex ante* regulation and were the regulatory standard is set when jointly use *ex ante* regulation and *ex post* strict liability;

- that the existence of the aforementioned tradeoff means that the regulatory standard can be set at a level that is greater than the socially optimal level of precaution; and

- that use of an *ex ante* regulation is complimentary with the use of *ex post* liability with punitive damages when those damages are set below the optimal level.

A final remark is that in the real world of controlling risks from environmental genotoxins complementary use of *ex ante* and *ex post* regulations seems to be more likely to succeed in a subjective sense than exclusive reliance on either type of regulation alone.

References

Cooter Robert D. and Thomas S. Ulen. 1988. *Law and Economics* (Scott, Foresman/Little, Brown: Glenview, IL).

Kolstad Charles D., Gary V. Johnson, and Thomas S. Ulen. 1987. "*Ex Post* Liability for Harm vs. *Ex Ante* Safety Regulation: Substitutes or Complements?" Working Paper Series on the Political Economy of Institutions No. 4 (Bureau of Economics and Business Research, University of Illinois, December, 1987).

Johnson Gary V. and Thomas S. Ulen. 1986. "Designing Public Policy Toward Hazardous Wastes: The Role of Administrative Regulations and Legal Liability Rules," *American Journal of Agricultural Economics*. pp. 1269-1270.

Johnson Gary V. and Thomas S. Ulen. 1988. "Liability and Administrative Regulation: Efficient Incentives for the Correction of Environmental Harms," (Paper presented at the Eastern Economic Association Annual Meeting, March, 1988).

End Notes

1. The authors are aware that for the most part genotoxins do not fall within the currently used legal definition of hazardous wastes. However, they do fall into the definition of special wastes used by USEPA and a number of states. Hence, we feel that hazardous wastes makes a good exemplar.

2. 42 U.S.C. §§ 6901-6907, 6911-6916, 6921-6931, 6941-6954, 6961-6964, 6971-6979, 6981-6986 (1982).

3. 42 U.S.C. §§ 9601-96575 (1982).

4. If this were the case the firm would cause harms to the point that the marginal cost for preventing the harm just equaled the marginal reduction in cost of the harms.

5. This is the case of σ_k approaching 0.

6. A derivation of the function for d^* and that for f_0 that follows in the next example is available from the authors upon request.

FOOD MARKETING POLICY CENTER
RESEARCH REPORT SERIES

This series includes final reports for contract research conducted by Policy Center Staff. The series also contains research direction and policy analysis papers. Some of these reports have been commissioned by the Center and are authored by especially qualified individuals from other institutions. (A list of previous reports in the series is given on the inside back cover.) Other publications distributed by the Policy Center are the Working Paper Series, Journal Reprint Series for Regional Research Project NE-165: *Private Strategies, Public Policies, and Food System Performance*, and the Food Marketing Issue Paper Series. Food Marketing Policy Center staff contribute to these series. Individuals may receive a list of publications in these series and paper copies of older Research Reports are available for $20.00 each, $5.00 for students. Call or mail your request at the number or address below. Please make all checks payable to the University of Connecticut. Research Reports can be downloaded free of charge from our website given below.

Food Marketing Policy Center
1376 Storrs Road, Unit 4021
University of Connecticut
Storrs, CT 06269-4021

Tel: (860) 486-1927
FAX: (860) 486-2461
email: *fmpc@uconn.edu*
http://www.fmpc.uconn.edu