Preventable Food Borne Illness with Dose-Response Damages: Optimal Sharing of Prevention Between Consumers and Processors and the Effect of Product Liability

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Abstract: As public concern for food safety burgeons concerned policy makers search for ways to manage the risk inherent to food consumption. Product liability laws may serve as efficient means to induce socially optimal levels of care or may efficiently complement regulation of potentially injurious activities. However, two characteristics common to many food borne illness cases are often not considered in the standard liability economics model that yields these prescriptions: dose-response damage functions and victim damage prevention.

This paper explores how dose-response relationships common to the biology and epidemiology of food borne illness may effect the shape of resulting social welfare functions and privately chosen prevention efforts under different liability rules when both processor and consumer affect damages. Dose-response damage functions yield social objectives with multiple local optima that may dictate diametrically opposite policy prescriptions in terms of prevention sharing between consumer and processor. Small changes in the relative efficacy of either party's preventative effort may dictate discrete changes in the socially optimal prescription. Similarly, legal rules that fail to recognize both parties' contribution to damage (e.g., strict processor or consumer liability) or incorrectly define due care standards for processor negligence or contributory negligence may cause private decisions to differ discretely from socially optimal behavior.

As public concern regarding food borne illness has burgeoned over the past decade concerned policy makers have been searching for ways to manage the pathogen-based risk inherent to food consumption. High profile events, such as the death of a young child and the severe illness of more than 70 others associated with the consumption of Odwalla apple cider containing E. coli O157:H7 in October of 1996, have helped to capture the public's attention and to increase their knowledge of food borne pathogens. The 1998 FDA Food Safety Survey quantifies this perception: 40 percent of US consumers believe food poisoning has become more common in the past five years and the percent of consumers who believe microbial organisms (e.g., *E. coli*) are a serious food safety problem has increased from 36 to 52 percent since 1993.

Food processing companies are also on the alert; high profile incidents cost companies millions of dollars in regulatory fines, tort liabilities and decreased product sales. The Odwalla case alone yielded a $1.5 million government fine (Consumer Product Litigation Reporter, 1998) and tort settlements greater than $12 million (Liability Week, 1998).

Economists have long recognized that product liability laws may serve as efficient means to induce socially optimal levels of care by potential injurers (Posner 1992) or may efficiently complement regulation of potentially injurious activity (Shavell 1984; Kolstad et al. 1990). However, much of this literature fails to incorporate two characteristics common to many food borne illness cases.

The first characteristic is that of a dose-response damage function. Most literature assumes that costly preventative effort is related to human damages via a convex function - initial efforts reduce damages considerably while the cost of total damage elimination approaches infinity. When damages are dictated by biological responses, as is the case in tracing the survival of harmful pathogens under different preventative effort treatments and tracing the decline of human health to increasing pathogen ingestion, the pertinent physical relationships often conform to a dose-response relationship that fails to meet these strict convexity assumptions. In dose-response relationships, increasing effort reduces damage first at a decreasing rate, then -- near the point of inflection -- at an increasing rate, and finally, once again at a decreasing rate.

The second characteristic pertinent to food borne illness that is somewhat underrepresented in the more general accident literature is that of bilateral control of the injurious activity, or as Shogren and Crocker (1991, 1999) call it, endogenous risk. For most food borne illness caused in the home, consumers have means available to alter the probability and severity of potential damages. While such bilateral settings are addressed by some of the product liability and tort economics literature (see Shavell (1980) and Posner (1992) for complete discussion of bilateral accidents and tort law under neoclassical assumptions and Shogren and Crocker (1991, 1999) for welfare measurement implications of endogenous risk), the interaction of victim prevention with other extensions of the standard neoclassical accident model have been minimal.

The purpose of this paper is to explore how dose-response relationships common to the biology and epidemiology of food borne illness may effect the shape of resulting social welfare functions and the effects of different liability rules on private choices of preventative effort by processor and consumer. The paper proceeds as follows. First, the mechanics of the dose-response damage function are developed and several possible functional forms are enumerated. Next, socially optimal levels of processor and consumer preventative effort are derived. Then a simple numerical example is described and solved for both the social optimal and for optimal private actions under several liability rules; this is done for the several damage functions. The efficacy of various tort rules and the characteristics of privately chosen effort levels under various damage functions is then discussed.

II. Model

Consider a model that consists of a processing sector and a consumer sector. The processor manufactures one unit of food and chooses $Q \in [0, Q_{\max}]$, the amount of effort to exert to prevent microbial infestation of its food. The consumer sector consumes all food and chooses $e \in [0, e_{\max}]$, the amount of preventative effort exerted during the food's transport, storage and preparation to reduce microbial infestation or impede its growth.

Microbial Growth and Food Borne Illness

Let q be the microbial density of food (e.g., log Colony Forming Units (CFU) per ml) at the time of consumption and assume $q = f(Q,e)$, where additional preventative effort decreases final microbial density when exerted by either the processor ($f_Q < 0$) or the consumer ($f_e < 0$). Microbial density is assumed to affect consumer well being because it increases the probability of food borne illness, z and increases the damage associated with the onset of such illnesses, D. Call the product of illness probability and illness damage the expected damage function, $d = zD = d(Q, e)$. Damage may cause market losses (productivity, time, medical expense) as well as non-market losses (pain and anxiety); d represents the expected monetarized value of all losses.

It is assumed for the remainder that expected damages are monotonically decreasing in both processor and consumer effort ($d_Q < 0$, $d_e < 0$). However, several different forms of the expected damage function are considered:

(A1) d is globally convex ($d_{ee} > 0$, $d_{QQ} > 0$, $d_{ee}d_{QQ} - (d_{eQ})^2 > 0$); e.g.,

$$d^c = a + a_e\tilde{e} + a_Q\tilde{Q} + a_{eQ}\tilde{e}\tilde{Q} + g_e\tilde{e}^2 + g_Q\tilde{Q}^2$$

where $\tilde{x} = (x_{\max} - w_x\, x) > 0$ for $x \in [e, Q]$; $e_{\max}$ and $Q_{\max}$ are the maximum amount of consumer and processor preventative effort possible; the w_x's are parameters dictating the relative efficacy of the two types of effort; the a_x's are weighting constants and $a = -d_{eQ}Q_{\max}e_{\max}w_e w_Q$.

Two other forms considered are based upon a quadratic dose-response (QDR) function:

$$d^{dr} = d_{\max}\left[1 - \frac{1}{1 + \exp\{a + a_e\tilde{e} + a_Q\tilde{Q} + a_{eQ}\tilde{e}\tilde{Q} + g_e\tilde{e}^2 + g_Q\tilde{Q}^2 - k\}}\right]$$

where $d_{\max}$ is the maximum damage level and k is a positive constant associated with the function's inflection point. Consider two sets of assumptions for this functional form:

(A2) $a_{eQ} = 0$, a_j and $g_j > 0$ for $j = e, Q$

(A3) $a_{eQ} > 0$, a_j and $g_j = 0$ for $j = e, Q$

Examples of functions that meet all three sets of assumptions are pictured in Figure 1.

Function (A1) meets all neoclassical expectations; it is monotonically decreasing in both arguments and globally convex. The dose-response functions are also monotonically decreasing but not globally convex. Under assumptions (A2) the function is quasi-convex; hence the iso-damage curves are convex to the origin and the elasticity of substitution is globally positive as in (A1). Under (A3) quasi-convexity does not hold, iso-damage curves are concave to the origin and the elasticity of substitution is globally negative.

The quadratic dose-response function is chosen because it is a common functional choice in microbiological and epidemiological studies. While such sigmoidal functions often have only scalar arguments (e.g., food borne pathogen growth modeled as a response to a single, controlled factor), efforts to expand the functional form to several factors (called secondary level modeling in this literature) are often implemented by substituting a polynomial expansion of several factors in place of the scalar argument. For example, Buchanan et al. (1993) fit experimentally controlled levels of temperature, salinity and pH to the growth rate of *E. coli* O157:H7 in several foods using a quadratic expansion of these arguments nested within a Gompertz function. While the Gompertz differs from the logistic form chosen in this paper, the elasticity of substitution between salinity and temperature, holding pH constant, is negative for many values of salinity, temperature and pH used in the Buchanan et al. study (1993).

The Consumer Sector

The consumer sector consists of a risk-neutral, representative consumer who maximizes:

$$w = w_0 - B(e) - p + L - d(Q,e)$$

where w is consumer wealth, w_0 is initial consumer wealth; $B(e)$ is the consumer's monetarized effort cost ($B_e > 0$ and $B_{ee} > 0$); p is food price; and L is the liability payment from processor to consumer as determined by the tort system. It is assumed that the consumer and processor hold unbiased expectations for the expected damages.

The Processing Sector

Following Shavell (1980) there is assumed to be one processor who acts competitively (hence zero expected profits). This processor chooses preventative effort to maximize profit:

$$p = p - c(Q) - L$$

where c(Q) is the processors' cost function with c_Q, $c_{QQ} > 0$ and L is the expected penalty to be paid by the processor.

Social Optimum

The socially optimal consumer and processor preventative efforts are defined as those that maximize consumer wealth while minimizing consumer and processor effort cost and expected damages:

(1) $\max_{Q,e} W^* = w_0 - B(e) - c(Q) - d(Q,e)$.

First-order optimality conditions for interior solutions are:

(2) $W_e^* = -B_e(e^*) - d_e(Q^*, e^*) = 0$

(3) $W_Q^* = -c_Q(Q^*) - d_Q(Q^*, e^*) = 0$.

Socially optimal preventative consumer effort (eq. 2) occurs when the consumer's marginal effort cost equals the expected marginal damage reduction from increased preventative effort. Optimal processor effort (eq. 3) requires the marginal effort costs to equal marginal expected damage improvements. Combining the two requirements will direct us to look for the tangency between the marginal rate of substitution (B_e/c_Q) and the marginal rate of technical substitution (d_e/d_Q). Second-order sufficiency conditions are met under (A1), but may not hold under (A2) and (A3) due to the lack of global convexity of the damage function. Hence, global optimality of the first-order conditions must be checked via alternative means; a global maximum is assumed to exist.

III. Social Optimum vs. Private Solutions with Torts: A Numerical Example

Consider the following example with consumer effort cost of $B(e) = e^2$; processor effort cost of $c(Q) = Q^2$ and expected damages under the three sets of assumptions (A1-A3) outlined above and pictured in Figure 1. All damage functions involve $Q_{\max}=e_{\max}=5$ and $a_e = a_Q = g_e = g_Q = 1$. The convex damage function (A1) in this example assumes $a_{eQ} = -0.2$ and $w_e = w_Q = 1$. For (A2) $a_{eQ} = 0$ while for (A3) $a_{eQ} = 1$. For the examples of (A2) and (A3) it is assumed that $d_{\max} = 50$, $w_Q = 0.95$, $w_e = 1.05$ and $k = 5$.

Social Optimum

The social objective functions subject to the three sets of assumptions for the damage function are pictured in Figure 2. When expected damages are convex, the social objective is unimodal and concave; the optimal solution requires that both consumer and processor contribute preventative effort in the mid-range of possible levels ($Q_1^* = 2.41$, $e_1^* = 3.16$) where the superscript stars denote socially optimal levels and subscript one denotes the set of assumptions for the damage function are given by (A1). Marginal changes in the relative efficacy or relative cost of one party's effort yield marginal changes in the optimal sharing of preventative effort.

When the function is a QDR under (A2), the social objective exhibits two local optima. The global optimum requires substantial preventative effort from both parties ($Q_2^* = 4.00$, $e_2^* = 3.78$) while the secondary local optimum involves no effort from either party ($Q_2' = 0$, $e_2' = 0$).

Which local optimum is the global solution depends upon total damages relative to total preventative costs summed across consumer and producer. If either or both types of preventative costs become large relative to damages, the social optimum tends toward zero effort from both; otherwise the social optimum tends toward high effort by both parties. Local optimum that occur away from the origin under (A2) are typically interior; hence social optimality dictates some sharing of the burden and cost of preventative effort between the parties as in the case of convex damage functions. This optimal sharing emerges because the damage isoquants under (A2) are convex to the origin; hence tangencies with the social iso-cost curves, which are concave to the origin, occur in the interior of the feasible effort region.

When the function is a quadratic dose-response (QDR) function under assumptions (A3), the social objective function also exhibits two local optima, though they are diametrical to the two local optima generated by assumptions (A2) (note the Figure 2b features a rotation of the axis relative to the other two figures). Comparing these we find the global optimum ($Q_3^* = 0.315$, $e_3^* = 4.41$) which features heavy reliance upon consumer effort and little processor effort. This result is driven, in part, by the assumption that consumer effort is more effective than processor effort in limiting damages ($w_e > w_Q$). However, note that the other local optimum ($Q_3^{'} = 4.786$, $e_3^{'} = 0.54$) features heavy reliance on processor effort and limited reliance on consumer effort - exactly opposite to the relative effort levels at the global optimum.

The QDR as under (A3) has a negative elasticity of substitution between consumer and processor effort. In order to maintain a constant level of damage, one needs to substitute an increasing amount of the consumer effort for every unit of processor effort that is not provided. Hence, corner solutions are likely to be the norm rather than the exception. In other words, because the damage isoquants bow out from the origin as do the social iso-cost curves, points of tangency and local optima tend toward a corner solution rather than an interior solution. Hence small changes in relative efficacy (which could be spurred by new technology) or relative marginal cost of preventative effort (which could be spurred by small changes in relative input prices) could lead to large changes in the socially optimal solution. As explored below, changes in liability rules can also lead to discrete changes in processor and consumer effort levels.

Strict Processor Liability

In the case of strict processor liability, an *ex-post* payment is made from processor to consumer in the amount of damages suffered regardless of the effort exerted by either party. Hence, consumer's effort under strict liability (e^L) is zero regardless of the form of the expected damage function because all damages are absorbed by the processor. Knowing this, processors choose effort to minimize production costs and damages.

Under (A1), processors choose marginally less effort than is socially optimal ($Q_1^L = 2.25 < Q_1^* = 2.41$) where the sign of the inequality stems from the negative cross-partial derivative of the expected damage function ($a_{eQ} = -0.2$). The marginal effectiveness of processor effort in terms of reducing expected damages increases as consumer effort is withdrawn. Because each unit of effort is more effective at reducing expected damages less is chosen when it is the only means of damage reduction.

Under (A2) strict liability leads the processor to choose a much lower level of effort than is socially optimal ($Q_2^L = 0 = Q_2^{'} < Q_2^* = 4.00$). In this case when the consumer does not add any effort and the elasticity of substitution between consumer and processor effort is positive and processor costs are increasing at an increasing rate, a sub-optimal level is chosen by the processor. The processor chooses to pay the consumer the amount of damages and exert no preventative effort because processor effort is complementary to consumer effort. Processor liability removes all incentives for consumer prevention, hence driving both privately chosen effort levels to the secondary social optimal at the origin.

Under (A3) and strict liability the processor chooses a level of effort that exceeds the socially optimal level ($Q_3^L = 4.86 > Q_3' > Q_3^* = 0.32$). Because the consumer is compensated for all damages and, due to bimodal nature associated with the dose-response form under (A3), the processor chooses a much higher level of effort. The negative elasticity of substitution between consumer and processor effort suggests joint efforts to reduce damage are replaced with solitary efforts with little additional effort on the part of the remaining party. Because consumers have no motive to provide effort under processor liability and because damages remain high compared to the costs absorbed by processor's preventative effort, processors choose to provide high effort.

Processor Negligence and Processor Liability with Consumer Contributory Negligence

Under processor negligence damages are absorbed by the consumer unless the processor's level of effort drops below the due care standard, in which case the processor absorbs all damages. When the due care standard is chosen such that it equals the socially optimal level of processor care relevant to each example, processors maximize profits by choosing the socially optimal level of care in all three examples. Given that processors act optimally, consumer optimal reactions in all three examples are to also choose effort at the socially optimal level. Even in the examples where the social objective function is not concave and bimodal, processor negligence induces socially optimal responses by both parties.

Under processor liability with a defense of consumer contributory negligence, the processor is held strictly liable for all consumer damages unless the consumer fails to exert due care (the consumer contributes to damage by being negligent), in which case the consumer absorbs all damages. When the consumer's due care standard is chosen to equal the socially optimal level, both the processor and the consumer maximize their individual objectives by choosing the socially optimal levels of effort in all three examples.

Even in the examples which feature dose-response damage functions, the tort arrangements of processor negligence and processor liability with a defense of contributory negligence yield socially optimal outcomes when due care standards are set equal to socially optimal levels of effort. Both sets of tort rules share the following feature: one party absorbs full liability for damages if it doesn't meet a due care standard and otherwise it absorbs no liability costs. Given that two social goals are present (regulating consumer and processor effort), two policy instruments are needed (Miceli and Segerson 1995). Assignment of liability to one party provides one of the needed instruments; if used alone it does not yield socially optimal results. Reassignment of liability if a due care standard is not met, such as is the case under processor negligence and a defense of contributory negligence, provides the second needed instrument which, if calibrated correctly, can yield socially optimal results.

Correct *ex ante* assignment of these standards of care and accurate *ex post* interpretation and evidentiary discover of the effort exerted by each party can be critical to social efficiency of tort arrangements (Endres 1989). Further research of the interaction of dose-response relationships with improper assignment or assessment of standards is warranted. Such improper assignment or interpretation may yield similar discrete changes from optimal outcomes as those associated with private decisions under strict processor liability and strict consumer liability.

III. Conclusions

Dose-response relationships between preventative effort and human damage and the shared effort of consumer and processor often required to limit pathogen-based risk in home prepared meals yield a regulatory problem that deviates from the standard problem explored in the liability economics literature. The dose-response damage functions common to pathogen-based production relationships may translate to social objectives with multiple local optima that dictate diametrically opposite policy prescriptions in terms of the sharing of preventative effort between consumer and processor. Small changes in relative efficacy of each party's preventative effort or small changes in the relative costs of preventative efforts may dictate large changes in the socially optimal prescription. Similarly, legal rules that fail to recognize both parties' contribution to damage (e.g., strict processor or consumer liability) or incorrectly define due care standards, may cause private decisions to differ discretely from socially optimal behavior.

Properly understanding food safety issues in the context of the emerging regulatory and liability environment will require enriching the modeling structure beyond the initial steps taken by this paper. Consumer perception of risk, probability of identifying and litigating food borne illness cases, the degree of market power held by processors and the interaction between *ex post* liability and *ex ante* regulation are all features pertinent to optimal social prescriptions for dealing with food safety issues. Furthermore, properly estimating the technological linkages from preventative effort to pathogen growth to human health effect to consumer damage is a major challenge that lies ahead for economic and physical scientists.

Figure 1. Damage Functions

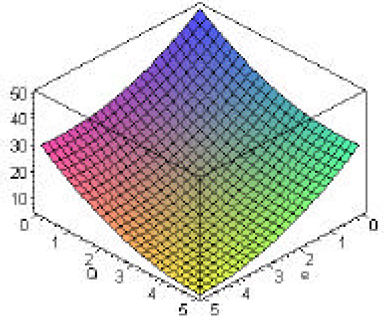

Figure 1a. Convex

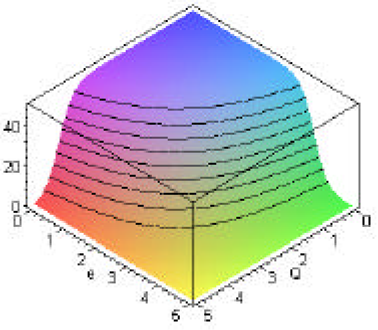

Figure 1c. Dose-Response with assumptions (A3), $a_{eQ} > 0$

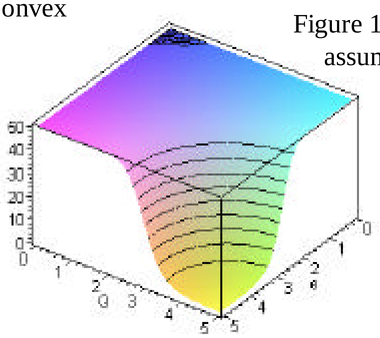

Figure 1b. Dose-Response with assumptions (A2), $a_{eQ} = 0$

Figure 2. Social Welfare Functions Associated with Different Damage Functions

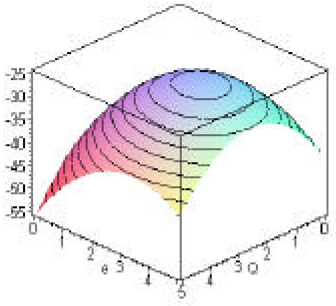

Figure 2a. Convex

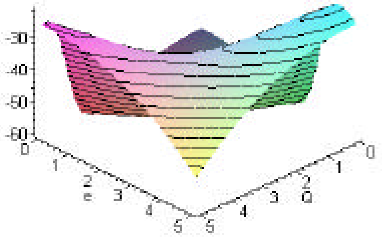

Figure 2c. Dose-Response with assumptions (A3), $a_{eQ} > 0$

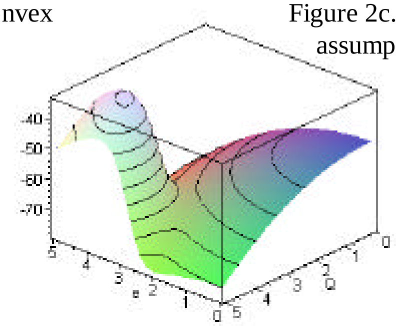

Figure 2b. Dose-Response with assumptions (A2), $a_{eQ} = 0$

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