Risk, Informational Asymmetry and Product Liability*

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1 Introduction

Product liability has acquired immense importance over the last 50 years. Most of the disputes involving product-caused injuries are governed by liability rules.[1] Product liability is said to be one of the fastest growing cost components that manufacturers and retailers are facing these days. The manufacturing of risky products leads two associated costs for the society: the accident costs and the insurance costs. A substantial expansion in the scope of product liability over the past thirty years has increased the cost of the third-party liability insurance.[2] Different product liability rules have different implications for the magnitude as also the allocation of thm accident costs and the insurance costs. Therefore, legal rules regarding product liability have important implications for both the producers as well as the consumers of risky products.

The implications of product liability rules have been widely studied in the fairly extensive literature on the subject. Mckean (1970), Oi (1973), Goldberg (1974), Hamada (1976), Spence (1977), Polinsky (1980), Marino (1988), Shavell (1987), Spulberg (1989), Boyd (1994), Miceli (1997), and Endres and Lüdeke (1998) are some of the many works that have studied various aspects of product liability. However, the focus of these studies has been on the accident costs. Accident costs depend on the care levels opted by producer firms as well the consumers. In addition, production/consumption level of the good in question also affects the accident costs. Therefore, accident costs can be excessive either on account of suboptimal choice of care levels or due to an inefficient choice of production/consumption levels by the parties. Focusing on only the accident costs, the above mentioned studies have shown the following: When the product market is competitive and consumers are completely

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[1] Geistfeld (2000), Harvey and Parry (2000).

[2] Until 1970s liability insurance was a small cost of doing business. See Viscusi (2006).

informed about the product risk, product liability rules are irrelevant for efficiency - the market relationship between consumers and firms ensures an efficient outcome. However, when consumers have incomplete information about the product risk, the market mechanism cannot lead to an efficient outcome. In that case, product liability is required for economic efficiency. (See Spence (1977), Polinsky and Rogerson (1983), Schwartz and Wilde (1985), Shavell (1987, pp. 52-53), Doughety and Reinganun (1997), Endres and L*ü*deke (1998), and Sunding and Zilberman (1998)).

It is important to note that the need for product liability arises because of the informational asymmetry that marks the product related accidents. While the producer firms are supposed to be completely informed about the product risk, consumers, on the contrary, are unlikely to know it correctly. This is so because consumers cannot observe the care taken by the producer firm while producing the product. Moreover, even when consumers could be informed about the care taken by the firm, they may still be incompletely informed about the risk. Because they may not know the accident loss function (the value of the expected loss for the given care levels) correctly. The literature on product liability rules has concluded that when the care is unilateral and consumers misperceive the accident-risk, the rule of strict liability is efficient. The rule of negligence, on the contrary, is said to be inefficient. Under this rule, consumers consume too much [too little] of the product when they underestimate [over-estimate] the risk. Polinsky (1980), Shavell (1987, ch 3, pp. 67-68) and Geistfeld (2000) are some of the notable contributions that establish these claims. In other words, it has been argued that, as far as the accident costs are concerned, economic efficiency requires the producers to bear the entire accident costs.

There is another body of literature for which our results are relevant. In some interesting works, the need for the tort liability of firms has been questioned. In these contributions, it has been argued that the informational asymmetry in which consumers lack the information about product risk might not be a problem that necessarily requires that firms be made liable for accident losses. Since, firms might signal the information regarding product related risk to consumers through price and warrantees etc. (for references see Bagwell and Riordan, 1991). In response to these contributions, many studies have argued that because of inadequate incentives (for informing consumers about the risk) on the part of firms and limited capability of consumers to process the information available, unregulated market cannot result in optimum care by firms and optimum consumption by consumers. Also, in some contexts consumers may not prefer better information about the quality of the product (Schlee, 1996).[3] Leaving aside the issues of signaling mechanisms and the relative merits of tort liability *vis-a-vis* other corrective mechanisms, we show that as long

[3]For arguments and discussion, besides afore-mentioned studies see Beales, Craswell and Salop (1981), Priest (1991), Grossman (1981), Landes and Posner (1987, ch. 10), Viscusi (1991), Burrows (1992), Schwartz (1995), Caves and Green (1996), Hamilton (1998), Arlen (2000), and Geistfeld (2000), etc.

as other mechanisms are imperfect in signaling the risk, there can be an efficiency-enhancing role for tort liability. Moreover, we show that even when firms have no liability in equilibrium, a suitable designed product liability rule can convey the information to consumers that is crucial for efficiency.

Finally, in view of our framework and results, we study the product liability rules that are prevailing in India.

The analysis is carried out in a partial-equilibrium framework. The framework of analysis, though very similar to the standard framework, is different on at least the following two counts. First, it is *unified* and *more* general than the standard framework. No assumptions are imposed on the costs of care and expected loss functions, apart from assuming the existence of a pair of care levels which minimizes the direct costs of accident. Second, it provides a formal analysis of the entire class of product liability rules in the context of bilateral care accidents where there is afore-mentioned informational asymmetry. Here it should be noted that the existing formal analyses have largely been undertaken *only* for the rule of negligence and the rule of strict liability. In Shavell (1980, 89) the efficiency of the rule of strict liability with the defense of the contributory negligence has been claimed without providing a formal proof. As a corollary of our results, we formally show that the claim in Shavell (1980, 87) holds in a broader framework.

2 Efficient Liability Rules: Unilateral Care

Reference for issues covered in this Section and other related issues see the book by Shavell (1987), Chapter 3 (on liability of firms).

2.1 Basics

We consider accidents that involve two parties, a consumer and the producer firm. Product-related accidents differ from the accidents generally considered under liability rules in that, in product-related accidents injurers (firms) and victims (consumers) engage in a market exchange. Moreover, this exchange is, supposedly, with the knowledge that the product might cause injuries to the consumer later on. However, the producer firms can take care to reduce the expected accident loss - in the next section we will allow both the producer firm as well as the consumer can take care to reduce the expected accident loss. The output of the firm and the amount of purchase made by the consumer are treated as their respective activity levels. It is assumed that in the event of an accident the entire loss falls on the consumer. We denote by:

x the cost of care taken by the firm, $x \geq 0$,
$X = \{x \mid x \text{ is the cost of some feasible level of care for the firm }\}$,

π the probability of occurrence of an accident,
D the loss in case an accident actually materializes, $D \geq 0$,
L the expected loss due to the accident. L is thus equal to πD,
L_c the expected accident loss as perceived by the consumer,[4]
n number of firms in the industry,
q number of units of the product produced by a firm,
$u_i(.)$ marginal consumption benefit to the i'th consumer from the product,
p the *market* price of one unit of the product,
$P(.)$ the inverse demand function for the industry,
$C(.)$ the cost of production function for a firm,
DAC the direct accident costs - the sum of costs of care and the expected accident loss, i.e., $DAC = x + L(x)$.

Analysis is undertaken in a simple competitive partial-equilibrium framework. We assume costs of care to be strictly increasing functions of care levels. As a result, the cost of care for a party also represents the level of care for that party. Therefore, X is the care choice set for the firm. Also, $0 \in X$. π and D are functions of x; $\pi = \pi(x)$, $D = D(x)$. L is thus a function of x; $L = L(x)$. Clearly, $L \geq 0$. L is a decreasing function of care level of each party. That is, a larger care by firm results in lesser or equal expected accident loss. Decrease in L can take place due to decrease in π or D or both. X and L are such that DAC minimizing care level is unique and it is denoted by x^*, where $x^* > 0$. That is, the term $x + L(x)$ is uniquely minimized at x^*. As a result, for all $(x) \neq x^*$, we have $x + L(x) > x^* + L(x^*)$. L_c is also a decreasing function of x.

Both firms and consumers are rational and risk-neutral. Moreover, the rationality of *each* party is a common knowledge.[5] The legal due care standard (level) for the firm, wherever applicable (say under the rule of negligence), is set at x^*. Also, $x \geq x^*$ means that the firm is taking at least the due care. In that case it will be called nonnegligent. $x < x^*$ would mean that it is taking less than the due care, i.e., it is negligent.

Marginal utility of the product is diminishing, i.e., $u_i'(.) < 0$. Firms are completely informed about the expected loss function $L(x)$. Consumers, on the other hand, are not completely informed about the expected loss; when the expected loss is $L(x)$, a consumer perceives it to be $L_c(x)$, where $L_c(.)$ may not be equal to $L(.)$. However, $L_c(x) \geq 0$ and satisfies corresponding properties for $L(.)$.

Note that x, π, D, and L are defined *per unit* of the product.

[4] L_c is the product of the probability of accident and the accident loss in the event of accident as are perceived by the consumer. See Assumption (A9) below.

[5] The assumption regarding the risk-neutrality of the party is relaxed in Singh (2009), wherein we consider insurance costs.

2.2 Social Objective

For the ease of exposition, the product is assumed to be homogeneous in all respects except the expected accident loss associated with the product use. The product market is assumed to be competitive; there are n identical firms each producing an output of q units. As was noted above, the direct accident costs *per unit* of product (DAC) are the sum of costs of care and the expected loss due to accident; DAC $= x + L(x)$. Therefore, the direct accident costs per firm are $q[x + L(x)]$, and the direct accident costs for the entire industry are $nq[x + L(x)]$.

$u_i(.)$ denotes consumer i's marginal consumption benefit from the product, and $u_i'(.) < 0$. $P(.)$ is the inverse demand function for the industry. It is assumed that the cost of production function, $C(q)$, is such that there is a unique positive output level at which a firm's average costs of production, $C(q)/q$, are minimized. This assumption is not necessary for our results to hold.[6] In this setup, the social surplus is equal to the total benefits from nq units of the product that consumers derive (approximated by the area under the industry's inverse demand curve) minus total costs of production (the sum of costs of production and the accident costs). The social objective is to choose x, q and n so as to maximize the social surplus

$$\int_0^{nq} P(z)dz - nC(q) - nq[x + L(x)]. \tag{1}$$

The first order conditions for q and n are given by (2) and (3), respectively.

$$P(nq) = C'(q) + x + L(x) \tag{2}$$

$$P(nq) = \frac{C(q)}{q} + x + L(x). \tag{3}$$

Let $\bar{q}(x)$ and $\bar{n}(x)$ uniquely solve (2) and (3) simultaneously. In other words, given x and y as levels of care taken by the consumer and the firm, when $n = \bar{n}$, at $\bar{q}$ marginal consumption benefit is equal to marginal total cost of the product - marginal cost of production plus DAC. That is, $\bar{q}$ is the optimal production level for the firm. Similarly, when $q = \bar{q}$, at $\bar{n}$ marginal consumption benefit is equal to average total cost of the product, i.e., $\bar{n}$ is the optimal number of the firm in the industry. Note that $\bar{q}$ and $\bar{n}$ are functions of x .

From (1), it is clear that the socially optimum care level, x^*, solves the following:

$$1 + L_x(x) = 0. \tag{4}$$

Let $\bar{q}(x^*) = q^*$ and $\bar{n}(x^*) = n^*$. That is, when firm takes efficient - DAC minimizing - care, q^* and n^*, respectively, denote the optimal level of production for a firm and the number of firms in the industry.

[6] However, if we take $C(q) = cq$, where $c > 0$, then equilibrium number of firms will be indeterminate.

3 Product Liability Rules

A *Product Liability Rules* (PLR) uniquely determines the proportions in which the consumer and the firm share the loss D, in the event of an accident, as a function of the proportions of their (non)negligence. Let I denote the closed unit interval $[0,1]$. Consider any X, L, and x^*.

As mentioned above, the legal standard for the firm, wherever applicable, is set at x^*. So, $x \geq x^*$, i.e., the firm is taking at least the due care and it would be called nonnegligent. When $x < x^*$, the firm is negligent. Similarly, for the consumer.

Formally, a PLR can be defined as a function

$$w_X : X \mapsto [0,1], \text{such that: } w_X \in [0,1]$$

where $w_X \geq 0$ [$w_Y \geq 0$] is the proportion of loss that the firm [the consumer] is required to bear. Clearly, $w_X + w_Y = 1$.

If an accident with a loss of D materializes, the court will require the firm to bear $w_X(x)D$, in the form of liability payment to be made to the consumer. w_X is determined by the PLR in force and is a function of x . The expected *accident* costs of a party are the sum of the cost of care taken by it plus its expected liability. A firm's expected accident costs, therefore, are: $x + w_X(x)\pi(x)D(x)$, i.e., $x + w_X(x)L(x)$. As far as the consumer is concerned, since he perceives the expected loss to be equal to $L_c(x)$, he will perceive the expected liability payment (made by the firm) to be equal to $w_X(x)L_c(x)$. Therefore, from a consumer's perspective his expected accident costs are: $L_c(x) - w_X(x)L_c(x)$, i.e., $w_Y(x)L_c(x)$.

The assumption of competitive market implies that p, the per unit market price of the product, is given for both the parties and is equal to the total marginal cost of production - marginal cost of production plus marginal expected liability of the firm. When consumers misperceive the risk, demand for the product is a function of the perceived full price. Given the relevant PLR and the level of care taken by the firm, 'perceived' full price *per unit* of product, $\bar{p}$, is equal to the market price plus the expected accident costs that the consumer expects to bear under the rule, i.e,

$$\bar{p} = p + w_Y(x)L_c(x).$$

Let,
$\bar{p}_i$ be the full price as perceived by the ith consumer.

Example 1 *Suppose there are two consumers.*

$ProductNo$	$u_1()$	$u_1 - \bar{p}_1$	$u_2()$	$u_2 - \bar{p}_2$
1	40	$40 - \bar{p}_1$	32	$32 - \bar{p}_2$
2	35	$35 - \bar{p}_1$	28	$28 - \bar{p}_2$
3	27	$27 - \bar{p}_1$	23	$23 - \bar{p}_2$
4	19	$19 - \bar{p}_1$	18	$18 - \bar{p}_2$
5	17	$17 - \bar{p}_1$	15	$15 - \bar{p}_2$
6	14	$14 - \bar{p}_1$	12	$12 - \bar{p}_2$

Suppose $x \in \{0, 2\}$, $L(0) = 20$, $L(2) = 5$. So, $x^* = 2$, $L(x^*) = 5$. Further, let $C(q) = cq = 10q$. So, the direct marginal cost of production $C'(q) = c = \frac{C(q)}{q} = 10$.

That is, for the fist consumer, the gross marginal utility of first unit of product is 40 but the perceived net marginal utility of the first product is $40 - \bar{p}_1$, and so on.

In the above example, it is clear that from social efficiency perspective, the firm should spend 2 on care level. Moreover, the consumption should be such that marginal utility form consumption is equal to the total marginal cost of production, which is $c + x^* + L(x^*) = 10 + 2 + 5 = 17$. That is, from social efficiency perspective, first consumer should consume 5 units but the second one should consume only 4 units.

However, the actual demand by consumers will be guided by $\bar{p}$ and not by the actual total marginal cost of production. In general the two will be different. (Why?) For instance, if $\bar{p}_1 = 20$, first consumer will consume only 4 units, leading to inefficiently low consumption.

In principle, $L_c(x)$ and therefore $\bar{p}$ can vary across consumers. Later on, we will allow $L_c(x)$ to vary across consumers, but as of now lets assume that $L_c(x)$ and therefore $\bar{p}$ are the same for all consumers.

Now, formally speaking, for given $\bar{p}$, i.e., given x, $w_Y(x)$ and $L_c(x)$, a consumer i's problem is to choose the quantity q_i to maximize his utility

$$\int_0^{q_i} u_i(z)dz - q_i[p + w_Y(x)L_c(x)] \tag{5}$$

resulting in the first order condition as

$$u_i(q_i) = p + w_Y(x)L_c(x) = \bar{p}.$$

That is, each consumer will keep on buying till her marginal utility is greater than or equal to the perceived full price $\bar{p}$. For instance, in the above example, if $\bar{p} = 19$, the first consumer will buy 4 units but second consumer will buy only 3 units of the product. So, total number of units bought will be 7, and from the seventh unit, i.e. at the margin, marginal utility is equal to $\bar{p}$.

Alternatively, given that $\bar{p} = 19$, if the two consumers were to choose total consumption level so as to maximize the sum of their utilities, they will end up buying exactly 7 units. You can verify that for any given $\bar{p}$, whether the consumers act individually or collectively, the same number of product will be demanded. Moreover, the marginal utility form last unit will be equal to $\bar{p}$.[7]

This means that given consumers' mis-perception about L, i.e., given L_c, $\bar{p}$, etc., the consumers' problem is equivalent to that of choosing total quantity Q to maximize

$$\int_0^Q P(z)dz - Q[p + w_Y(x)L_c(x)]. \tag{6}$$

The first order condition for Q is

$$P(Q) = p + w_Y(x)L_c(x) = \bar{p}. \tag{7}$$

Note that when consumers choose their demand for the product rationally, each consumer's marginal benefit, $u_i(z)$, is equal to $P(Q)$. Therefore, (6) is maximized w.r.t. Q if *ceteris-paribus* each consumer chooses his demand for the product rationally. In other words, other things remaining the same, rational choice by individual consumers would lead to the maximization of consumers' surplus. In our analysis, however, this maximization is constrained by the informational asymmetry.

As far as firms are concerned, given the PLR a firm's problem is to choose the quantity q and the level of care x so as to maximize its profits

$$pq - C(q) - q[x + w_X(x)L(x)]. \tag{8}$$

The first order condition for q is

$$p = C'(q) + x + w_X(x)L(x). \tag{9}$$

Free entry assumption implies that profit of each firm is zero, i.e.,

$$pq = C(q) + q[x + w_X(x)L(x)], i.e.,$$

$$p = \frac{C(q)}{q} + x + w_X(x)L(x). \tag{10}$$

From (8) it is clear that regardless of its choice of production level the firm chooses x that minimizes its expected accident costs, $x + w_X(x)L(x)$.

[7]if a social planner were to take $\bar{p} = 19$, he will allow consumption of 7 units - 4 by the first consumer and 3 by the second one.

3.1 Full information

Suppose, the situation is as in example 1 above, i.e., $C'(.) = c = 10$, $x^* = 2$, $L(x^*) = 5$. Moreover, consumer can observe the care level, x, and the expected loss, $L(x)$, correctly. This means that $L_c(x) = L(x)$, and

$$\bar{p} = p + L(x)$$

Let us consider specific rules to find out the equilibrium outcome.

3.1.1 Rule of No Liability

Suppose firms are not liable for accident loss caused by their products. Will they still opt for efficient care level x^*? Will the consumption decisions of consumers be efficient?

Suppose firm A does not take care but firm B chooses x^*; that is A chooses 0 as care level and B spends 2 on care. Suppose, firm A charges price $p_A = 10$, i.e., it just recovers its direct production cost. But, B will have to charge at least 12. Let firm B charge a price of 13; note $13 > c + x^* = 10 + 2$. By assumption, consumers observe x as well as $L(x)$. So, $\bar{p}_A = 10 + 20$, but $\bar{p}_B = 13 + 5 = 18$. Clearly, firm A will loose all its customers to firm B. In contrast, if A were to choose $x^* = 2$ as care level and charge price of 12.5, it can attract all costumers of B.

You can verify that in a competitive equilibrium all firms will choose x^* and $p = c + x^* = 12$ - if a firm decides to choose care different from x^*, and/or, charges a price different from 12, it will loose its customers. Therefore, $\bar{p} = p + L(x^*) = 12 + 5 = 17$. This means that the individual consumption decisions are also efficient.

3.1.2 Rule of Negligence Liability

You can verify that under the rule of negligence in a competitive equilibrium all firms will choose x^* and $p = c + x^* = 12$. Moreover, $\bar{p} = p + L(x^*) = 12 + 5 = 17$. This means that the individual consumption decisions are also efficient.

3.1.3 Rule of Strict Liability

You can verify that under the rule of strict liability in a competitive equilibrium all firms will choose x^*. Moreover, individual consumption decisions will also be efficient.

Question 1 *What will be the market price under the rule of strict liability?*

3.2 Partial information

Suppose, the situation is as in example 1 above, i.e., $C'(.) = c = 10$, $x^* = 2$, $L(x^*) = 5$. Moreover, consumer can know the expected loss function, $L(x)$, correctly. However, they cannot observe the care level, x.

3.2.1 Rule of No Liability

Again, suppose firm A does not take care but firm B chooses x^*; that is A chooses 0 as care level and B spends 2 on care. Now, firm A can sell its product at price of 10, but firm B will have to charge 12. However, since consumers cannot observe the care level opted by the two firm, they cannot tell the different between the products of two firms. So, the will not be willing to pay higher price for product of firms B. Sensing this, B will not choose care greater than 0. Rational consumers will therefore infer that all firms have taken 0 care. So, the market price $p = c = 10$. This means that $L_c(0) = L(0)$, and

$$\bar{p} = p + L(0) = 10 + 20 = 30$$

That means there will be inefficiently low consumption by the consumers. However, notice that the consumption decisions are efficient given the care levels.

3.2.2 Rule of Strict Liability

You can verify that under the rule of strict liability in a competitive equilibrium all firms will choose x^*, even when consumers cannot observe the actual care choice made by the firms. Moreover, individual consumption decisions will also be efficient.

Question 2 *What will be the market price under the rule of strict liability?*

3.2.3 Rule of Negligence

This Subsection is OPTIONAL

Assume that consumers cannot observe the actual care choice made by the firms. Answer the following questions, for the rule of negligence

Question 3 *Will the firms choose x^*? Will the individual consumption decisions be efficient?*

Exercise 1 *Critically examine the claims regarding rule of negligence in Shavell (1987).*

3.3 Asymmetric information

Suppose, the situation is as in example 1 above, i.e., $C'(.) = c = 10$, $x^* = 2$, $L(x^*) = 5$. However, consumer do not observe the care level, x. Moreover, they do not know the expected loss function, $L(x)$.

3.3.1 Rule of No Liability

Again, suppose firm A does not take care but firm B chooses x^*; that is A chooses 0 as care level and B spends 2 on care. Now, firm A can sell its product at price of 10, but firm B will have to charge 12. However, since consumers cannot observe the care level opted by the two firm, they cannot tell the different between the products of two firms. So, the will not be willing to pay higher price for product of firms B. Sensing this, B will not choose care greater than 0. Rational consumers will therefore infer that all firms have taken 0 care. So, the market price $p = c = 10$.

Moreover, in general $L_c(0) \neq L(0)$ will hold. Also,

$$\bar{p} = p + L_c(0) = 10 + L_c(0)$$

That is, there will be inefficient consumption by the consumers.

Question 4 *Are the individual consumption decisions efficient, for the given the care level opted by the firm?*

3.3.2 Rule of Strict Liability

You can verify that under the rule of strict liability in a competitive equilibrium all firms will choose x^*, even though consumers do not observe the actual care choice made by the firms as well as mis-perceive the expected loss function, i.e., $L_c(.) =\neq L(.)$. Moreover, individual consumption decisions will also be efficient.

Question 5 *What will be the market price under the rule of strict liability?*

Question 6 *What will be the perceived full price for consumers?*

3.3.3 Rule of Negligence

This Subsection is OPTIONAL

Assume that consumers cannot observe the actual care choice made by the firms. Moreover, they mis-perceive the expected loss function, i.e., $L_c(.) =\neq L(.)$. Answer the following questions, for the rule of negligence

Question 7 *Will the firms choose x^*? Will the individual consumption decisions be efficient?*

Exercise 2 *Critically examine the claims regarding rule of negligence in Shavell (1987).*

4 The Social Optimization Problem: Bi-lateral Care

First of all, we specify notations and assumptions.[8]

[8] This section is a simpler and abridged version of Singh (2009), 'Risk, Informational Asymmetry and Product Liability', *Pacific Economic Review*. Also, see section on Product Liability in book by Miceli (1997)

4.1 Basics

In this section, we extend the model to allow both the producer firm as well as the consumer to care to reduce the expected accident loss. The output of the firm and the amount of purchase made by the consumer are treated as their respective activity levels. As before, it is assumed that in the event of an accident the entire loss falls on the consumer. We denote by:

x the cost of care taken by the firm, $x \geq 0$,
$X = \{x \mid x$ is the cost of some feasible level of care for the firm $\}$,
y the cost of care taken by the consumer, $y \geq 0$,
$Y = \{y \mid y$ is the cost of some feasible level of care for the consumer$\}$,
π the probability of occurrence of an accident,
D the loss in case an accident actually materializes, $D \geq 0$,
L the expected loss due to the accident. L is thus equal to πD,
L_c the expected accident loss as perceived by the consumer,[9]
n number of firms in the industry,
q number of units of the product produced by a firm,
$u_i(.)$ marginal consumption benefit to the i'th consumer from the product,
p the *market* price of one unit of the product,
$P(.)$ the inverse demand function for the industry,
$C(.)$ the cost of production function for a firm,
DAC the direct accident costs - the sum of costs of care and the expected accident loss, i.e., $DAC = x + y + L(x, y)$.

Analysis is undertaken in a simple competitive partial-equilibrium framework. We assume:
(A1): Costs of care to be strictly increasing functions of care levels. As a result, the cost of care for a party also represents the level of care for that party. Therefore, Y is the care choice set for the consumer, and X is the care choice set for the firm. Also, $0 \in X$ and $0 \in Y$.
(A2): π and D are functions of y and x; $\pi = \pi(x, y)$, $D = D(x, y)$.
(A3): L is thus a function of y and x; $L = L(x, y)$. Clearly, $L \geq 0$.
(A4): L is a decreasing function of care level of each party. That is, a larger care by either party, given the care level of the other party, results in lesser or equal expected accident loss. Decrease in L can take place due to decrease in π or D or both.
(A5): X, Y, and L are such that DAC minimizing pair of care levels is unique and it is denoted by (x^*, y^*), where $x^* > 0$, and $y^* > 0$. That is, the term $x + y + L(x, y)$ is uniquely minimized at (x^*, y^*). As a result, for all $(x, y) \neq (x^*, y^*)$, we have

$$x + y + L(x, y) > x^* + y^* + L(x^*, y^*).$$

[9] L_c is the product of the probability of accident and the accident loss in the event of accident as are perceived by the consumer. See Assumption (A9).

(A6): Both firms and consumers are rational and risk-neutral. Moreover, the rationality of *each* party is a common knowledge.The assumption regarding the risk-neutrality of the party is relaxed in Section 4, wherein we consider insurance costs.
(A7): The legal due care standard (level) for the firm, wherever applicable (say under the rule of negligence), is set at x^*. Similarly, the legal standard of care for the consumer, wherever applicable (say under the rule of strict liability with defense), is y^*. Also, $x \geq x^*$ means that the firm is taking at least the due care. In that case it will be called nonnegligent. $x < x^*$ would mean that it is taking less than the due care, i.e., it is negligent. Likewise, for the consumer.
(A8): Marginal utility of the product is diminishing, i.e., $u_i'(.) < 0$.
(A9): Neither party observes the care taken by the other party. Firms are completely informed about the expected loss function $L(x, y)$. Consumers, on the other hand, are not completely informed about the expected loss; when the expected loss is $L(x, y)$, a consumer perceives it to be $L_c(x, y)$, where $L_c(.)$ may not be equal to $L(.)$. However, $L_c(x, y) \geq 0$ and satisfies (A4).

Note that (A1)-(A9) are standard assumptions in the economic analysis of liability rules. Moreover, it should be noted that x, y, π, D, and L are defined *per unit* of the product.

4.2 Social Objective

For the ease of exposition, the product is assumed to be homogeneous in all respects except the expected accident loss associated with the product use. The product market is assumed to be competitive;[10] there are n identical firms each producing an output of q units. As was noted above, the direct accident costs *per unit* of product (DAC) are the sum of costs of care by the two parties and the expected loss due to accident; DAC $= x + y + L(x, y)$. Therefore, the direct accident costs per firm are $q[x + y + L(x, y)]$, and the direct accident costs for the entire industry are $nq[x + y + L(x, y)]$. $u_i(.)$ denotes consumer i's marginal consumption benefit from the product, and $u_i'(.) < 0$. $P(.)$ is the inverse demand function for the industry. It is assumed that the cost of production function, $C(q)$, is such that there is a unique positive output level at which a firm's average costs of production, $C(q)/q$, are minimized. This assumption is not necessary for our results to hold.[11] In this setup, the social surplus is equal to the total benefits from nq units of the product

[10] As is the case with our model, it is shown in Epple and Raviv (1978) and Geistfeld (2000) that as long as DAC per unit of product are independent of the output level, the results obtained in a competitive setting will hold more or less even when the market is not competitive. For the effects of market-power on the output and the choice of care by firms and the related issues see Beals, Craswell and Salop (1981), Schwartz and Wild (1982), Polinsky and Rogerson (1983), Marino (1988 a, b), Spulber (1989, pp.408-410), Faulhaber and Boyd (1989), and Boyd (1994).

[11] However, if we take $C(q) = cq$, where $c > 0$, then equilibrium number of firms will be indeterminate.

that consumers derive (approximated by the area under the industry's inverse demand curve) minus total costs of production (the sum of costs of production and the accident costs). The social objective is to choose x, y, q and n so as to maximize the social surplus

$$\int_0^{nq} P(z)dz - nC(q) - nq[x + y + L(x, y)]. \tag{11}$$

The first order conditions for q and n are given by (2) and (3), respectively.

$$P(nq) = C'(q) + x + y + L(x, y) \tag{12}$$

$$P(nq) = \frac{C(q)}{q} + x + y + L(x, y). \tag{13}$$

Let $\bar{q}(x, y)$ and $\bar{n}(x, y)$ uniquely solve (12) and (13) simultaneously. In other words, given x and y as levels of care taken by the consumer and the firm, when $n = \bar{n}$, at $\bar{q}$ marginal consumption benefit is equal to marginal total cost of the product - marginal cost of production plus DAC. That is, $\bar{q}$ is the optimal production level for the firm. Similarly, when $q = \bar{q}$, at $\bar{n}$ marginal consumption benefit is equal to average total cost of the product, i.e., $\bar{n}$ is the optimal number of the firm in the industry. Note that $\bar{q}$ and $\bar{n}$ are functions of x and y.

Remark 1: Since accident costs are linear in output, the socially optimum levels of x and y are independent of the quantity of the product produced/consumed (see eq. (1)-(3)). In other words, economic efficiency requires that the parties' care levels minimize DAC, regardless of the consumption level of the consumer and the production level of the firm. Furthermore, (2) and (3) imply that $C'(q) = C(q)/q$. That is, $\bar{q}$ is the efficient level of output for the form, irrespective of the choice of x and y.

Let $\bar{q}(x^*, y^*) = q^*$ and $\bar{n}(x^*, y^*) = n^*$. That is, when both the parties take efficient - DAC minimizing - care, q^* and n^*, respectively, denote the optimal level of production for a firm and the number of firms in the industry.

Definition: Product Liability Rules A Product Liability Rule (PLR) uniquely determines the proportions in which the consumer and the firm share the loss D, in the event of an accident, as a function of the proportions of their (non)negligence. Let I denote the closed unit interval $[0, 1]$. Consider any Y, X, L, and (x^*, y^*).

In view of Assumption (A7), the legal standard for the firm, wherever applicable, is set at x^*. So, $x \geq x^*$, i.e., the firm is taking at least the due care and it would be called nonnegligent. When $x < x^*$, the firm is negligent. Similarly, for the consumer.

Formally, a PLR can be defined as a function

$$w_X : X \times Y \mapsto [0, 1], \text{such that: } w_X \in [0, 1]$$

where $w_X \geq 0$ [$w_Y \geq 0$] is the proportion of loss that the firm [the consumer] is required to bear. Clearly, $w_X + w_Y = 1$.

4.3 Competitive Equilibrium

If an accident with a loss of D materializes, the court will require the firm to bear $w_X(x,y)D$, in the form of liability payment to be made to the consumer. w_X is determined by the PLR in force and is a function of x and y. The expected *accident* costs of a party are the sum of the cost of care taken by it plus its expected liability. A firm's expected accident costs, therefore, are: $x + w_X(x,y)\pi(x,y)D(x,y)$, i.e., $x + w_X(x,y)L(x,y)$. As far as the consumer is concerned, since he perceives the expected loss to be equal to $L_c(x,y)$, he will perceive the expected liability payment (made by the firm) to be equal to $w_X(x,y)L_c(x,y)$. Therefore, from a consumer's perspective his expected accident costs are: $y + L_c(x,y) - w_X(x,y)L_c(x,y)$, i.e., $y + w_Y(x,y)L_c(x,y)$.

The assumption of competitive market implies that p, the per unit market price of the product, is given for both the parties and is equal to the total marginal cost of production - marginal cost of production plus marginal expected liability of the firm. When consumers misperceive the risk, demand for the product is a function of the perceived full price. Given the relevant PLR and the level of care taken by the firm, 'perceived' full price *per unit* of product is equal to the market price plus the expected accident costs that the consumer expects to bear under the rule, i.e, $p + y + w_Y(x,y)L_c(x,y)$. Therefore, a consumer i's problem is to choose the quantity q_i and the level of care y to maximize his utility

$$\int_0^{q_i} u_i(z)dz - pq_i - q_i[y + w_Y(x,y)L_c(x,y)] \tag{14}$$

resulting in the first order condition as

$$u_i(q_i) = p + y + w_Y(x,y)L_c(x,y).$$

This means that given consumers' mis-perception about L, consumers' problem is equivalent to that of choosing the quantity Q and the care y to maximize

$$\int_0^{Q} P(z)dz - pQ - Q[y + w_Y(x,y)L_c(x,y)]. \tag{15}$$

The first order condition for Q is

$$P(Q) = p + y + w_Y(x,y)L_c(x,y). \tag{16}$$

Note that when consumers choose their demand for the product rationally, each consumer's marginal benefit, $u_i(z)$, is equal to $P(Q)$. Therefore, (5) is maximized w.r.t.

Q if *ceteris-paribus* each consumer chooses his demand for the product rationally. In other words, other things remaining the same, rational choice by individual consumers would lead to the maximization of consumers' surplus. In our analysis, however, this maximization is constrained by the informational asymmetry.

Similarly, given the PLR and the care taken by the consumer, a firm's problem is to choose the quantity q and the level of care x so as to maximize its profits

$$pq - C(q) - q[x + w_X(x, y)L(x, y)]. \tag{17}$$

The first order condition for q is

$$p = C'(q) + x + w_X(x, y)L(x, y). \tag{18}$$

Free entry assumption implies that profit of each firm is zero, i.e.,

$$pq = C(q) + q[x + w_X(x, y)L(x, y)], i.e.,$$

$$q = \frac{C(q)}{q} + x + w_X(x, y)L(x, y). \tag{19}$$

From (14)&(15) it is clear that the optimum level of care for the consumer is independent of his levels of consumption. In other words, a rational and risk-neutral consumer chooses y that minimizes his expected accident costs, $y + w_Y(x, y)L_c(x, y)$, regardless of his level of consumption. Analogous argument in view of (17)&(18) implies that given y, the firm chooses x that minimizes its expected accident costs, $x + w_X(x, y)L(x, y)$.

An *equilibrium* is defined as a tuple $< \hat{Q}, \hat{p}, \hat{q}, \hat{n}, \hat{x}, \hat{y} >$ such that: $\hat{Q} = \hat{n}\hat{q}$; and $\hat{Q}$, $\hat{p}$, and $\hat{q}$ satisfy (16), (18) and (19), respectively; $\hat{x} = arg\ min_{x \in X}\{y + w_X(x, y)L(x, y)\}$, and $\hat{y} = arg\ min_{y \in Y}\{y + w_Y(x, y)L_c(x, y)\}$.

Now, from (16)&(18) in equilibrium we have

$$P(Q) = P(nq) = C'(q) + x + y + w_Y(x, y)L_c(x, y) + w_X(x, y)L(x, y) \tag{20}$$

and from (16) and (19) we get

$$P(Q) = P(nq) = \frac{C(q)}{q} + x + y + w_Y(x, y)L_c(x, y) + w_X(x, y)L(x, y). \tag{21}$$

5 Efficiency of PLRs

In this section, we restrict the analysis only to the accident costs. In other words, we study the incentives that various product liability rules create for the parties for the choice of the care levels and the production/consumption levels.

When consumers misperceive the risk, the actual output level per firm and the number of firms in the industry are given by (20) and (21). However, for the given levels of care opted by the consumers and the firms, the socially optimum level of production per firm and the number of firms in the industry are given by (12) and (13), respectively. Generally the solution to (20)&(21) will be different from that of (12)&(13). (20)&(21), however, imply that $C'(q) = C(q)/q$, i.e., in equilibrium output per firm is efficient (Remark 1). But, from (20) and (21) it follows that even if we assume that both the parties have opted for efficient care levels, when consumers misperceive the risk, i.e., when $L_c \neq L$ the number of firms in the industry is not necessarily efficient. Therefore, even if we exclude the insurance costs and restrict our attention only to the accident costs, a PLR may cause inefficiency on the following two counts: (a) it may induce the parties to take inefficient care, and (b) it may induce inefficient (total) production and hence consumption.

Remark 2: Let $L_c \neq L$. If under a PLR $w_Y = 0$ or $w_X = 1$ in equilibrium, (20)&(21) will exactly be the same as (12)&(13). Therefore, both the quantity produced by the firms as well as the number of firms in the industry will be efficient. This, however, will not be the case when $w_Y \neq 0$.

As regards to care levels, a rule is said to be efficient iff in equilibrium it induces efficient care by both the parties. To be efficient on both the counts, the rule should also induce efficient output for the industry.

Definition 1: *Efficient Product Liability Rule*

A PLR, w_X, is said to be efficient with respect to the accident costs iff, in equilibrium it simultaneously induces the choice of the efficient care levels by both the parties, the efficient output per firm and the efficient number of firms in the industry. Formally, w_X is efficient for given Y, X, L, (x^*, y^*), and $C(q)$, iff: (x^*, y^*) is a unique Nash equilibrium (N.E.); and in equilibrium q^* and n^* solve (20) and (21), simultaneously. A PLR, w_X, is defined to be ***efficient*** iff it is efficient for every possible choice of Y, X, L, (x^*, y^*), and $C(q)$.

In the following, we discuss efficiency properties of PLRs when there is informational asymmetry vis-a-via the expected loss function, i.e., when $L_c \neq L$. Formally, we show that when $L_c \neq L$, a PLR w_X is efficient if it satisfies the condition of 'negligent consumer's liability' (NCL).

Definition 2: *Condition of Negligent Consumer's Liability (NCL):*

A PLR, w_X, is said to satisfy the condition NCL if its structure is such that (i) whenever the consumer is nonnegligent, i.e., whenever he has taken at least the due care, the entire loss in the event of accident is borne by the firm, irrespective of the level of care taken by the firm, and (ii) when the consumer is negligent and the firm is not, the entire loss in the event of accident is borne by the consumer. Formally, a PLR w_X satisfies condition NCL if:

$$\begin{aligned} y \geq y^* &\Rightarrow w_X = 1 \\ x \geq x^* \& \ y < y^* &\Rightarrow w_X = 0 \end{aligned}$$

Remark 3: A PLR may specify the due care standards for both the consumer and the firm, or for only the consumer, or for only the firm, or for neither of the parties. It should be noted that a PLR can satisfy the condition NCL only if it specifies the due care standards for the consumer; it may or may not set the due care standard for the firm. When a PLR does not specify the due care standard for the consumer, it cannot satisfy the condition NCL.

Lemma 1 *A PLR is efficient for every possible choice of Y, X, L, (x^*, y^*), L_c, and $C(q)$ only if*

$$y \geq y^* \Rightarrow w_X = 1.$$

Note that under the condition NCL, when both the parties are nonnegligent it is the firm that is liable for the *entire* accident loss. Therefore a PLR can violate the condition '$y \geq y^* \Rightarrow w_X = 1$' by making the consumer liable for a fraction of the accident loss when both the parties are nonnegligent. When this holds, the consumer will bear at least a fraction of the accident loss even when he opts for the efficient care level. This, in view of Remark 2, implies that even if both parties take efficient care, the production levels and consumptions levels will be inefficient.

As argued before, in order to satisfy the condition NCL, a PLR has to specify the due care standards for (i) both the consumer as well as the firm, or (ii) for only the consumer. Suppose a PLR belongs to subclass (i). In that case, the due levels of care are part of the common knowledge. Recall that the due levels of care are assumed to be set at levels that are appropriate for efficiency, i.e., at x^* and y^*. Therefore, under a PLR belonging to subclass (i), consumers - because of this common knowledge - get to know of DAC minimizing pair, (x^*, y^*), from the legal rule itself.[12] That is, under PLRs in subclass (i), the expected loss function as perceived by a rational consumer, L_c, may not be identical with L but will be such that (x^*, y^*) uniquely solves

$$\min_{x,y}\{x + y + L_c(x, y)\}.$$

[12]As a matter-of-fact some rules, such as the rules of negligence with the defense, comparative negligence, strict liability with the dual defense, specify the due care standard for both the parties.

Formally, if a PLR specifies the due care standards for both the parties, L_c is as described in the following Property.

Property P1: If a PLR specifies the due care standards for both the parties, L_c is such that: $(\forall (x,y) \in X \times Y)$

$$\begin{aligned} x^* + y^* + L_c(x^*, y^*) &\leq x + y + L_c(x,y), \\ (x,y) \neq (x^*, y^*) &\Rightarrow [x^* + y^* + L_c(x^*, y^*) < x + y + L_c(x,y)] \end{aligned}$$

Of course, when $L_c = L$, L_c the above Property holds. However, depending on the PLR in question and consumers' risk perception, L_c may or may not satisfy (P1); e.g., if PLR does not set due care standards for both parties, or sets them at levels different from x^* and y^*, respectively.

Next, we will show that the NCL is a sufficient condition for the efficiency of any PLR, even when consumers misperceive the risk, i.e., even when $L_c \neq L$. First of all note the following Lemmas.

Lemma 2 *If a PLR satisfies the condition NCL then for every possible choice of X, Y, L, (x^*, y^*), and L_c satisfying (P1), (x^*, y^*) is a N.E.*

Proof: Let the PLR, w_X, satisfy the condition NCL. Take any arbitrary X, Y, L, (x^*, y^*) and any L_c satisfying (P1). As w_X satisfies the condition NCL,

$$w_X(x^*, y^*) = w_X^* = 1.$$

Moreover, for all x and y

$$x \geq x^* \ \& \ y \geq y^* \Rightarrow [w_X(x,y) = w_X^* = 1].$$

Let $x = x^*$ be opted by the firm. Then, for all $y \geq y^*$, the expected accident costs of the consumer are $y + w_X(x^*, y)L_c(x^*, y) = y$. So, if the consumer chooses y^* his expected accident costs are only y^*. Now, consider a choice of $y' \neq y^*$ by the consumer. First, consider the case when $y' > y^*$. In this case his expected accident costs clearly are y', and he will be strictly worse-off choosing y' rather than y^*. Now, consider the case $y' < y^*$. For $y' < y^*$, the expected accident costs of the consumer are $y' + w_Y(x^*, y')L_c(x^*, y')$, i.e., $y' + L_c(x^*, y')$, as when $y' < y^*$, $w_Y(x^*, y') = 1$ by condition NCL. But, the choice of y' can be better than that of y^* for the consumer only if $y' + L_c(x^*, y') < y^*$, i.e., only if $x^* + y' + L_c(x^*, y') < x^* + y^*$. This implies $x^* + y' + L_c(x^*, y') < x^* + y^* + L_c(x^*, y^*)$. But, in view of (P1) this is a contradiction.
Thus, given that x^* is opted by the firm, y^* is a best response by the consumer.

Next, let y^* be opted by the consumer. This, in view of condition NCL implies that the expected costs of the firm are $x + L(x, y^*)$. By assumption, $x + y^* + L(x, y^*)$

and therefore $x + L(x, y^*)$ is uniquely minimized at x^*. That is, given that y^* is opted by the consumer, x^* is a best response by the firm.

Hence (x^*, y^*) is a N.E. $\square$

Note: Reading beyond is this page is OPTIONAL

Lemma 3 *If a PLR satisfies condition NCL then for every possible choice of X, Y, L, (x^*, y^*), and L_c satisfying (P1),*

$$(\forall(\bar{x},\bar{y}) \in X \times Y)[(\bar{x},\bar{y}) \ \ \textit{is a N.E.} \rightarrow (\bar{x},\bar{y}) = (x^*, y^*)].$$

Proof: Let PLR w_X satisfy condition NCL. Take any arbitrary X, Y, L, (x^*, y^*), and any L_c satisfying (P1). Suppose $(\bar{x},\bar{y}) \in X \times Y$ is a N.E. $(\bar{x},\bar{y})$ is a N.E. implies that

$$\bar{y} + w_Y(\bar{x},\bar{y})L_c(\bar{x},\bar{y}) \leq y^* \tag{22}$$

as $w_Y(\bar{x}, y^*) = 0$ by condition NCL. And,

$$\bar{x} + w_X(\bar{x},\bar{y})L(\bar{x},\bar{y}) \leq x^* + w_X(x^*,\bar{y})L(x^*,\bar{y}) \tag{23}$$

Adding (22) and (23)

$$\bar{x} + \bar{y} + w_Y(\bar{x},\bar{y})L_c(\bar{x},\bar{y}) + w_X(\bar{x},\bar{y})L(\bar{x},\bar{y}) \leq x^* + y^* + w_X(x^*,\bar{y})L(x^*,\bar{y}) \tag{24}$$

Case 1: $\bar{y} \geq y^*$:
When $\bar{y} \geq y^*$, $w_Y(\bar{x},\bar{y}) = 0$ and $w_X(\bar{x},\bar{y}) = 1$. Therefore, from (24), $(\bar{x},\bar{y})$ is a N.E. $\rightarrow$ $\bar{x}+\bar{y}+L(\bar{x},\bar{y}) \leq x^*+y^*+L(x^*,\bar{y})$. Now, $\bar{y} \geq y^* \rightarrow L(x^*,\bar{y}) \leq L(x^*,y^*)$. Therefore, we get $\bar{x}+\bar{y}+L(\bar{x},\bar{y}) \leq x^*+y^*+L(x^*,y^*)$. But, $\bar{x}+\bar{y}+L(\bar{x},\bar{y}) \geq x^*+y^*+L(x^*,y^*)$, as (x^*,y^*) is DAC minimizing. This implies that $(\bar{x},\bar{y})$ can be a N.E. only if $(\bar{x},\bar{y}) = (x^*,y^*)$. Thus,

$$\bar{y} \geq y^* \& (\bar{x},\bar{y}) \ \textit{is a N.E.} \rightarrow (\bar{x},\bar{y}) = (x^*,y^*). \tag{25}$$

Case 2: $\bar{y} < y^*$:
Subcase 1: $\bar{x} \geq x^*$: In this case $w_Y(\bar{x},\bar{y}) = 1$, $w_X(\bar{x},\bar{y}) = 0$ and $w_X(x^*,\bar{y}) = 0$. So, (24), reduces to $\bar{x}+\bar{y}+L_c(\bar{x},\bar{y}) \leq x^*+y^*$. Thus, $\bar{x}+\bar{y}+L_c(\bar{x},\bar{y}) \leq x^*+y^*+L_c(x^*,y^*)$, which is a contradiction in view of (P1). Therefore,

$$\text{if} \ \ \bar{x} \geq x^* \& \bar{y} < y^*, \ \text{then} \ (\bar{x},\bar{y}) \ \ \text{cannot be a N.E.} \tag{26}$$

Subcase 2: $\bar{x} < x^*$: Suppose $w_X(\bar{x},\bar{y}) = \bar{w}_X$. Let

$$w_Y^* = \frac{y^* - \bar{y}}{(x^* - \bar{x}) + (y^* - \bar{y})} \ \ \textit{and} \ \ w_X^* = \frac{x^* - \bar{x}}{(x^* - \bar{x}) + (y^* - \bar{y})}.$$

There are two possible cases: (i) $\bar{w}_X \geq w_X^*$, or (ii) $\bar{w}_X < w_X^*$. When (i) holds, from (23), $(\bar{x},\bar{y})$ is a N.E. $\rightarrow \bar{x} + \bar{w}_X L(\bar{x},\bar{y}) \leq x^*$. That is, we get $\bar{w}_X L(\bar{x},\bar{y}) \leq x^* - \bar{x}$, i.e., rearranging

$$\frac{x^* - \bar{x}}{(x^* - \bar{x}) + (y^* - \bar{y})} L(\bar{x},\bar{y}) \leq x^* - \bar{x}, \ \ \textit{as} \ \ \bar{w}_X \geq w_X^* \rightarrow w_X^* L(\bar{x},\bar{y}) \leq \bar{w}_X L(\bar{x},\bar{y}).$$

So, when (i) holds $(\bar{x}, \bar{y})$ is a N.E. $\rightarrow \bar{x} + \bar{y} + L(\bar{x}, \bar{y}) \leq x^* + y^*$, i.e.,

$$\bar{x} + \bar{y} + L(\bar{x}, \bar{y}) \leq x^* + y^* + L(x^*, y^*),$$

which is a contradiction because $(\bar{x}, \bar{y}) \neq (x^*, y^*)$.

When (ii) holds, i.e., when $\bar{w}_X < w_X^*$, $\bar{w}_X + \bar{w}_Y = 1 = w_X^* + w_Y^*$ implies $\bar{w}_Y > w_Y^*$. When $\bar{w}_Y > w_Y^*$, from (22) $(\bar{x}, \bar{y})$ is a N.E. $\rightarrow \bar{w}_Y L_c(\bar{x}, \bar{y}) \leq y^* - \bar{y}$. Thus, in this subcase, $(\bar{x}, \bar{y})$ is a N.E. implies $w_Y^* L_c(\bar{x}, \bar{y}) \leq y^* - \bar{y}$, i.e.,

$$\frac{y^* - \bar{y}}{(x^* - \bar{x}) + (y^* - \bar{y})} L_c(\bar{x}, \bar{y}) \leq y^* - \bar{y}, \quad i.e.,$$

$$\bar{x} + \bar{y} + L_c(\bar{x}, \bar{y}) \leq x^* + y^*,$$

which is a contradiction in view of (P1). Therefore,

$$if \quad \bar{x} < x^* \& \bar{y} < y^*, \ then \ (\bar{x}, \bar{y}) \ cannot \ be \ a \ N.E. \tag{27}$$

Finally, (25) - (27) $\rightarrow [(\bar{x}, \bar{y})$ is a N.E. $\rightarrow (\bar{x}, \bar{y}) = (x^*, y^*)]$. $\Box$

Theorem 1 *A PLR is efficient for every possible Y, X, L, (x^*, y^*), L_c, and $C(q)$, if it satisfies the condition NCL and sets due care standards for both parties.*

Theorem 1 establishes that as far as the accident costs are concerned, PLRs that satisfy the condition NCL and set due care standards (at efficient levels) for both parties are efficient for every possible application, irrespective of consumers' misperception about the product risk. The above results show that if a PLR sets due care levels for both parties then Property P1 holds. Therefore, under it (x^*, y^*) is a unique N.E. That is, the consumer and the firm will opt for the DAC minimizing care levels, i.e., y^* and x^*, respectively. Now, under NCL a choice of y^* by the consumer implies that $w_Y = 0$. In other words, in equilibrium the consumer will always opt for y^*, and consequently will not bear any risk, making the risk-misperception irrelevant. Also, when $[w_X = 1]$ market price will fully reflect the product-risk.

What is called the rule of strict liability with the defense of dual contributory negligence meets the requirement of Theorem 1. Under this rule, liability assignment is as follows:

$$\begin{aligned} y \geq y^* \quad &\Rightarrow \quad w_X = 1 \\ x \geq x^* \& \ y < y^* \quad &\Rightarrow \quad w_X = 0 \\ x < x^* \& \ y < y^* \quad &\Rightarrow \quad w_X = 1 \end{aligned}$$

On the contrary, it can be shown that PLRs that violate the condition NCL cannot be efficient in all applications. One violation of the condition NCL implies that when y^* is opted by the consumer and x^* is opted by the firm, $w_Y > 0$ or $w_X < 1$, i.e., less than full liability of the firm and at least some risk-bearing by consumers. From (20)&(21) and the proof of Theorem 1, this results in inefficiency. Therefore, as long as the market mechanisms are imperfect in signalling the product-risk, i.e, as long as $L_c \neq L$, there will be inefficiency in the absence of the residual liability of the firms, and product liability rules can play an efficiency enhancing role.

Theorem 2 *A PLR is efficient for every possible Y, X, L, (x^*, y^*), L_c, and $C(q)$, if it satisfies the condition NCL.*

Formal Proof of Theorem 2: Suppose a PLR, denoted by w_X, satisfies the condition NCL. Given that w_X satisfies the condition NCL, there are two mutually exclusive possibilities: (i) w_X specifies the due care levels for both the parties, (ii) w_X specifies the due care level for only the consumer.
Case 1: Suppose (i) holds. In this case, as is shown by Theorem 1, the PLR is efficient.
Case 2: Suppose (ii) holds. In this case as the care level of the firm is irrelevant from legal point of view, the liability assignment cannot be conditioned on its care level; it will have to be conditioned only on the care level of the consumer. Therefore, in this case the condition NCL would imply that the rule, w_X, be such that

$$y \geq y^* \rightarrow w_X = 1 \ \& \ y < y^* \rightarrow w_X = 0$$

Under such a liability assignment, (x^*, y^*) is a unique N.E. To see why, note that the consumer will never opt for $y > y^*$, i.e., he will always choose a y such that $y \leq y^*$. So, any N.E., will have $y \leq y^*$ opted by the consumer.

If the consumer opts for y^* his expected accident costs are simply y^*; on the other hand, if he opts for some $y < y^*$ his expected accident costs will be $y + L_c(x, y)$, where x is the care level opted by the firm. Under reasonable conditions it can be shown that opting for y^* is a strictly dominant strategy for the consumer. Otherwise, you can assume that for all $y < y^*$ $y + L_c(x^*, y) > y^*$ holds.

It is easy to see that given y^* opted by the consumer, x^* is a uniquely best response for the firm. Again, (x^*, y^*) is a unique N.E.

Therefore, if a PLR satisfies the condition NCL, then for every X, Y, L, (x^*, y^*), and L_c, (x^*, y^*) is a unique N.E.

Now, (x^*, y^*) is a unique N.E. and condition NCL imply that in equilibrium $w_X = 1$ and $w_Y = 0$. As a consequence, (20)&(21) will be identical with (12)&(13).

This implies that q^* and n^* will solve (20)&(21), simultaneously (Remark 2). Therefore, w_X is efficient for every X, Y, L, (x^*, y^*), and L_c. $\square$

The rule of the strict liability with the defense of contributory negligence holds the consumer liable iff he was negligent. Therefore the rule can be defined as: $(y \geq y^* \rightarrow w_X = 1)$ and $(y < y^* \rightarrow w_X = 0)$. Clearly, the rule satisfies the condition NCL and therefore is efficient. Therefore, as an implication, Theorem 2 provides a formal proof to the claim about the efficiency of the rule of strict liability with the defense of contributory negligence by Shavell (1980, 87) in a broader context. Based upon the fulfillment or otherwise of the condition NCL, we immediately get the following corollary 1 from Theorem 2.

Corollary 1 *The rule of strict liability with the defense of contributory negligence as well as the rule of strict liability with the defense of dual contributory negligence, are efficient (in terms of care levels, output per firm and the number of firms in the industry) for every X, Y, L, (x^*, y^*), L_c and every $C(q)$. On the other hand, the rules of no liability, strict liability, negligence, negligence with the defense of contributory negligence, and comparative negligence are not efficient.*

Remark 4: Both the rule of strict liability with the defense of contributory negligence as well as the rule of strict liability with the defense of dual contributory negligence satisfy the condition NCL. However, it should be noted that the condition is less restrictive than either of these rules. In particular, the condition does not impose any restriction on liability assignment when both the parties are negligent. Therefore, in principle it is possible to design more rules that satisfy the condition and therefore are efficient.

So far we have been focusing on the efficiency both in terms of care levels as also the output/consumption levels. Next, we show that if we exclusively focus on the the efficiency in terms of care levels, it is possible to derive a weaker condition for efficiency of a PLR. As noted earlier, several rules set the due standards of care for both the parties. If a PLR sets the due care standards for both the parties then for any arbitrary L_c the following claim holds.

Theorem 3 *A PLR, w_X, is DAC minimizing for every X, Y, L, (x^*, y^*), and L_c, if it sets the due care standards for both the parties, and is such that*

$$[g < 1 \rightarrow [w_X(g, 1) = (1, 0)], \; \& \; h < 1 \rightarrow [w_X(1, h) = (0, 1)]], \; \& \; [w_X(x^*, y^*) = (1, 0) \; \textit{or} \; (0, 1)].$$

Suppose a PLR is such that 1) it sets the due care standards for both the parties, 2) it holds only one party (any of the two) to be fully liable when both the parties are nonnegligent, and 3) when one party is negligent and the other is not then the solely negligent party bears all the losses. Theorem 3 says that irrespective of consumers' misperceptions of the product risk, such a PLR is efficient as far as direct accident costs are concerned. For proof see the Appendix. Note that under a PLR, as in the statement of Theorem 3, L_c will satisfy the Property (P1). When $w_X(x^*, y^*) = (0, 1)$ hold, i.e., when the firm is the residual loss bearer, the rule satisfies the condition NCL and therefore is DAC minimizing. When $w_X(x^*, y^*) = (1, 0)$, i.e., even when the consumer is the residual loss bearer, the proof shows that both the parties will take efficient care under the rule.

Remark 1 *Note that under a PLR satisfying NCL, in equilibrium $w_Y = 0$, therefore, $\bar{p} = p$. This means that even if we allow the marginal utilities, u, and risk perceptions, $L_c()$, to vary across consumers, the above results will still hold.*