Correlated accidents

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Abstract

This paper investigates cases in which harms are statistically correlated. When parties are risk averse, correlation plays an important role in the choice between liability rules. Specifically, positively correlated harms favor a liability rule that spreads the risk over a multitude of parties, as in the negligence rule. Negatively correlated harms favor a liability rule that pools risks together, as in strict liability. The same applies when parties can purchase costly insurance (first party or third party).

This policy recommendation is in line with current products liability law, which places design defects and warning failures under a *de facto* negligence regime.

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At the beginning of 2013, attorney Lance Cooper, hired by the family of a woman who had died in a car crash, discovered that the faulty ignition switch in the Chevy Cobalt she was driving was the likely cause of the crash. The faulty switch could accidentally turn the car off while in motion and prevent the airbags from deploying. This discovery was bad news for thousands of Chevy Cobalt owners (as well as owners of many other GM car models), who realized that their cars were not as safe as they had expected. This was very bad news for GM as well, as it indicated that a swarm of lawsuits was about to descend. By the end of 2015, 4400 claims had been filed against GM. The company has acknowledged that the faulty switch was the cause of 124 deaths, 17 serious injuries and 258 less serious injuries.[1] The faulty switch is a typical design defect affecting a whole product line and thus causing *positively correlated* harms: i.e., once one case of harm occurs, more cases of harms are likely to occur.

In a very different case, a consumer (Mr. Dolinki) fell ill after drinking a bottle of Squirt (a soft drink) in which, upon examination, the decomposed body of a mouse was found.[2] The discovery of the mouse was bad news for Mr. Dolinki and the soft drink producer, but not for other Squirt consumers (in fact, no other mice were found in similar bottles). Unlike the GM case, in which the defect was in the design, here the flaw was in the manufacturing process (the mouse accidentally fell in the bottle before it was filled). Manufacturing defects usually do not affect the whole product line and tend to cause *uncorrelated* harms. Under some conditions, they can even cause negatively correlated harms. Consider a case in which it is known that, for some reasons, only one bottle of a soft drink will contain a mouse. Here the discovery of the contaminated bottle provides positive news to the other consumers: harms are *negatively correlated* (if one harm occurs, fewer additional harms are likely to occur) .

From a legal point of view, the fundamental difference between the first example (a design defect) and the second one (a manufacturing defect) is that the former is subject to a negligence rule, while the latter is subject to strict liability. When the defect lies in the design, producers are normally exonerated from liability if no safer design was

[1] By April 2016, GM had spent nearly $600 million to settle claims (Automotive News, April 20, 2016).

[2] *Shoshone Coca-Cola Bottling Co. v. Dolinski,* 420 P.2d 855 (Nev. 1966).

available at reasonable costs (under the so called "risk-utility test"). If, instead, the defect lies in the manufacturing process, the fact that the defect could not have been detected by a (reasonable) quality control system is not a defense against liability.[3]

In this paper, I argue that the differential treatment of design and manufacturing defects can be grounded in the statistical structure of the two types of defect: positively correlated harms call for the use of a negligence rule, negatively correlated harms for the use of a strict liability rule.

The latter proposition is rather intuitive. The degree of correlation across harms affects the variance of the total losses caused by the injurer (or, alternatively, the variance of the number of claims she will face). If correlation is positive, total losses tend to be either very small or very large (large variance). If correlation is negative, total losses tend not to vary much (low variance). If injurers care about the variability of their payoffs, i.e., if they are *averse to risk*, as most people are, then liability law should induce *loss spreading* when harms are positively correlated and *loss pooling* when harms are negatively correlated. This should occur, however, without thwarting the injurer's incentives to take care. As I will show below, negligence law provides the injurer with incentives to take due care and disperses the (residual) loss among the victims. So it fits well with positively correlated harms. Strict liability places all the losses with the injurer: it provides the injurer with incentives to take care and, at the same time, pools the risks. So, it fits well with negatively correlated harms.

By focusing on the statistical structure of harm, this paper offers a novel contribution to the classic debate about which liability rule is socially preferable.[4]

In Section 1, I present a model in which one injurer can cause harm to n potential victims. Injurer and victims are assumed to be averse to risk.[5] To simplify the exposi-

[3]See *Restatement of the Law (Third) Torts: Products Liability*, § 2. Note that the differential treatment of design and warning defects is acknowledged in the *Third Restatement*, but not in the *Second* (§ 402A). The ALI reporters provide several reasons for this differential treatment in § 2 cmt. *a*, but none appear fully convincing (see Wright (2007)).

[4]See Shavell (2007), Schaefer and Mueller-Langer (2009), and references therein.

[5]Empirically, it has been shown that risk aversion tends to be stronger when losses come with a low probability, as is likely the case with most tortuous accidents (see Wakker (2010) for an introduction to contemporary risk theory). In Section 4, I review the reasons why firms might also display risk aversion.

tion, I take a second order approximation (Arrow-Pratt) of the utility functions of the parties, yielding a simple payoff structure: parties care about the mean and the variance of potential losses (harm or liability expenditure). I compare social welfare under the strict liability and the negligence rules. The outcome of this comparison turns out to revolve around a few basic factors: the injurer's disposition toward risk, the victims' average dispositions toward risk, the average correlation across harms, and the number of potential victims.

If harms are uncorrelated, each one can be treated independently of the others.[6] In Section 3, I show that in this case strict liability dominates negligence if, and only if, the injurer is less averse to risk than the potential victims. If harms are statistically interdependent, the sign of correlation matters: positive correlation shifts the balance toward strict liability; negative correlation toward negligence. I show that negligence is definitely superior if the number of potential victims is large and harms are positively correlated. Conversely, strict liability is definitely superior when the negative correlation between harms is sufficiently strong.

The previous results do not rely on any assumption about the relationship between the level of care exerted by the injurer and the degree of correlation between harms (more care can increase or decrease correlation). A more structured example is provided in Section 4, where I consider a situation in which, in the case of an accident, only k individuals out of n are affected. This case captures several interesting scenarios, including the transportation of hazardous substances and quality control in manufacturing.

The k/n model can display both negative and positive correlation: when k is small, harms are negatively correlated; when k is large, harms are positively correlated. Furthermore, it can be shown that correlation decreases with the probability of an accident: if this probability is close to nil, correlation is positive; if this probability is close to one, correlation is negative.[7] In line with the previous observations, I show that strict liabil-

[6]Note, in this respect, how strict liability cannot work here as a risk spreading arrangement (a mutual insurance). In mutual insurance, each participant bears a small share of the total loss. Under strict liability, all the loss is shouldered by one party.

[7]The information that individual j was involved in an accident provides individual i with two pieces of information: i) the accident has occurred, and ii) j was involved. When the probability of the accident is small, the first piece of information has greater weight and the initial information is bad news for individual i. The opposite applies when the probability of the accident is large.

ity is preferable if k is small and/or the probability of the accident is large; negligence is preferable if k is large and/or the probability of the accident is small.

Let us consider a case where, in the transportation of hazardous substances, an accident can take place at any point along the route (of equal population density). When the accident occurs, k individuals are affected. The previous result suggests that, given k, strict liability should apply if, and only if, the activity entails a high probability of an accident. When the accident is nearly certain, strict liability is able to perfectly neutralize uncertainty: all the loss is placed on the injurer, who will bear it with near certainty. Under negligence, instead, n people would bear the uncertainty of not knowing whether they will belong to the set of the k victims. This proposition provides a partial rationale for current liability law, which places "abnormally dangerous" activities under a strict liability regime.[8]

Of even greater interest is the application of the k/n model to the manufacturing process. Here I suppose that the quality control system fails with some probability (which depends on the level of care of the injurer). If this is the case, exactly k items (out of n) will be defective and consumers will be harmed. The results of the k/n model suggest that production failures that tend to affect most items (large k) should be subject to a negligence rule, while those affecting a relatively small number of items (small k) should be subject to strict liability. As mentioned above, this proposition strongly resonates with current product liability law, which places design defects and warning failures - which tend to affect the whole product line - under a negligence regime, and manufacturing defects - which only affect a few items in the line - under strict liability.

The products liability case is fully explored in Appendix A2, where I consider a perfectly competitive market in which firms decide the level of safety of their products. Negative correlation among defects creates economies of scale, positive correlation diseconomies of scale. Again, negative correlation tilts the balance in favor of strict liability, while positive correlation tilts it in favor of the negligence rule. Because the allocation

[8] See *Restatement (Third) of Torts: Liability for Physical and Emotional Harm (2010),* § 20. Note, however, that under the law, activities are regarded as abnormally dangerous either because they entail a high probability of accident or because they tend to cause harms of sizable dimension. The "risk allocation" rationale only applies to high probability activities.

of risk matters only if parties are averse to it, at the end of Section 4, I review the reasons that lead firms to display risk aversion.

Finally, in Section 5, I consider a case in which parties can obtain insurance on the market. Because insurance comes with positive loading, the optimal policy (for first or third party insurance) includes a deductible, as is common in practice. When losses are positively correlated, liable injurers chose a smaller deductible. I show that the main results also apply, verbatim, to this case.

Literature. As some of the early (and most acute) critics of products liability have observed, positive correlation across harms can make liability insurance prohibitively expensive. Because of this, they argue that is inefficient to require firms to always compensate consumers for harms caused by product defects (Epstein (1985) and Priest (1987)).[9] The focus of this scholarship is the positive correlation that arises out of legal changes ("socio-legal risk") affecting, for example, the notion of defectiveness or the eligibility of claims. Such changes can either spawn or wipe out thousands of similar claims at the same time (see Baker and Siegelman (2013) and Hylton (2013)). In this paper, I build on these early insights and develop a formal model in which (positively or negatively) correlated claims arise from the nature of the harmful activity itself, rather than from legal change. Furthermore, I focus on the impact of correlation on the payoff of the parties, rather than on the availability/cost of insurance. From the latter point of view, it should be noted that positive correlation across claims is problematic for third-party *as well as* first-party insurance.

The impact of risk aversion on liability law is investigated by Shavell (1982). In his model, the injurer faces one potential victim, so the issue of correlation does not arise. Nell and Richter (2003) address the case of perfectly positively correlated risks under CARA utilities. They show that optimal damages converge to nil if the number of victims grows to infinity. In such a situation (and assuming that care is constrained above), negligence approximates the first best, as it places the full loss on the victims. This result does not carry over to the case in which the injurer can purchase costly

[9]The target of this criticism is the "enterprise liability" theory, which spurred the expansion of corporate liability in the 70s and 80s. This theory is based on the idea that corporations are in a better position than consumers to bear the cost of injuries.

insurance. In this paper, I compare negligence and strict liability for any number of victims, acknowledging that both liability rules are first-best inefficient ("first best" ensues when the policymaker can control at the same time the level of care and the allocation of the loss). In turn, my results also apply to the costly insurance case. The case of perfectly positively correlated harms is also addressed by Franzoni (2015), where I investigate the impact of risk and ambiguity aversion on the optimal features of liability law.

1 The structure of accident risk

Let us consider first the case in which an injurer can harm n individuals $\{1, 2, ..., n\} = N$. Let A_j be a random variable that takes value 1 if individual j is involved in an accident, and value 0 otherwise. The probability that $A_j = 1$ depends on the amount of resources x spent by the injurer in prevention ("care").[10] For simplicity, I assume that the probability of accident is the same for all $j \in N$: $pr\left(A_j = 1 \mid x\right) = p\left(x\right)$ with $p'\left(x\right) < 0$. Greater care reduces the probability of accident. For all individuals, let the magnitude of harm be equal to h.

For each individual, the expected harm associated with the accident prospect is $E\left(A_j h \mid x\right) = p\left(x\right) h$, while the variance of individual harm is

$$Var\left(A_j h \mid x\right) = p\left(x\right)\left(1 - p\left(x\right)\right) h^2. \tag{1}$$

The variance of total harm, $\sum_{j=1}^{n} A_j h$, depends on the correlation across accidents.

[10] My results would not change if x were decomposed into a vector of victim-specific levels of care. Note, further, that the qualitative results of this paper carry over to the case in which care affects both the distribution and the extent of harm.

We have

$$
\begin{aligned}
Var\left(\sum_{j=1}^{n} A_j h \mid x\right) &= \sum_{j=1}^{n}\sum_{k=1}^{n} Cov\left(A_j h, A_k h \mid x\right) \\
&= nVar\left(A_j h \mid x\right) + \sum_{j=1}^{n}\sum_{k\neq j}^{n} Cov\left(A_j h, A_k h \mid x\right) && (2) \\
&= Var\left(A_j h \mid x\right) n \left[1 + (n-1)\frac{\sum_{j=1}^{n}\sum_{k\neq j}^{n} Cov\left(A_j h, A_k h \mid x\right)}{(n-1)\, nVar\left(A_j h \mid x\right)}\right] && (3) \\
&= Var\left(A_j h \mid x\right)\;\; n\left[1 + (n-1)\,\rho(x)\right], && (4)
\end{aligned}
$$

where

$$
\rho(x) = \frac{1}{(n-1)\, n}\sum_{j=1}^{n}\sum_{k\neq j}^{n}\frac{Cov\left(A_j, A_k \mid x\right)}{Var\left(A_j \mid x\right)},
$$

is the average (Pearson) coefficient of correlation across accidents.

If accidents are **independent** of each other, then $\rho(x) = 0$. If harms are **positively correlated**, then $\rho(x) > 0$. If harms are **negatively correlated**, then $\rho(x) < 0$.

I make no specific assumption about the source of correlation and the relationship between care and correlation. So, for example, harms can be positively correlated because, when an accident occurs, many individuals are inevitably affected (e.g., an airplane crash), or because a common prevention method is applied to many risks - if it fails with one, it is likely to fails with all (e.g., when similar faulty implants are placed in different patients). So, correlation can increase or decrease with care.[11]

[11] In an insightful discussion of the implications of correlation for liability insurance, Shavell (2014) mentions the relevant case in which positive correlation arises because risks share a common parameter whose level is uncertain ex-ante ("parameter uncertainty"). This type of correlation is compatible with my model, which also accounts for negative correlation. So, one can have situations in which a high parameter for one risk implies a low parameter for another risk (e.g., if a substance turns out to be effective in treating A, then it cannot be effective in treating B).

The upper bound of $\rho(x)$ is unity. For the lower bound, note that

$$\frac{Cov(A_j, A_k \mid x)}{Var(A_j \mid x)} = \frac{E(A_j A_k \mid x) - E(A_j \mid x)E(A_k \mid x)}{E(A_j^2 \mid x) - (E(A_j \mid x))^2}$$

is minimal when $E(A_j A_k \mid x) = 0$ (i.e., j and k cannot be harmed at the same time). If this applies to all $j \neq k \in N$, we get

$$\begin{aligned}\inf \rho(x) &= \frac{1}{(n-1)n} \sum_{j=1}^{n} \sum_{k \neq j}^{n} -\frac{(E(A_j \mid x))^2}{E(A_j \mid x) - (E(A_j \mid x))^2} = \\ &= -\frac{E(A_j \mid x)}{1 - E(A_j \mid x)} = -\frac{p(x)}{1 - p(x)}.\end{aligned}$$

So, the lower bound of the correlation coefficient depends positively on $p(x)$. Furthermore, since here at most one individual can be harmed, $p(x)$ cannot be large: $\sum_{i=1}^{n} p(x) \leq 1$ implies: $p(x) \leq 1/n$. So the lower bound cannot be less than

$$\inf \rho(x)\big|_{p(x)=1/n} = -\frac{1/n}{1 - 1/n} = -\frac{1}{n-1}. \tag{5}$$

When correlation reaches its minimum, $\rho(x) = -\frac{1}{n-1}$, the variance of total harm collapses to nil (see eq. (4)).

2 Liability rules

Let us consider the negligence rule first.

Negligence

Under negligence, courts set a standard of care $\overline{x}$. If the injurer meets the standard, she is not liable for the harm caused (her conduct in not unreasonably dangerous). Unless the standard is set at an exorbitant level, the injurer has an incentive to meet it and avoid liability. So, I assume that $x = \overline{x}$.[12]

[12]Note that the same outcome could be achieved by means of safety regulation. In this sense, the results of this paper highlight the conditions under which regulation outperforms (strict) liability.

Potential victims only differ with respect to their aversion to risk. The expected utility of a potential victim j is

$$EU_{V_j}(\overline{x}) = (1 - p(\overline{x}))\, u_{V_j}(i_V) + p(\overline{x})\, u_{V_j}(i_V - h),$$

where i_V is his level of income, and u_{Vj} his utility function.

For small losses, the disposition of individuals toward risk is independent of income (see Pratt (1964)).[13] The payoff of individual j (his certainty equivalent) can be written as:

$$C_{V_j}(\overline{x}) = i_V - p(\overline{x})\, h - \tfrac{1}{2}\alpha_j Var(A_j h \mid \overline{x}). \tag{6}$$

The certainty equivalent is equal to income i_V, less expected harm $p(\overline{x})\, h$, less a risk premium $\frac{1}{2}\alpha_j Var(A_j h \mid \overline{x})$ which depends on the Arrow-Pratt degree of absolute risk aversion of the individual, $\alpha_j \geq 0$, and the variance of harm (eq. 1).[14]

The payoff to the injurer is

$$C_I(\overline{x}) = i_I - \overline{x},$$

where i_I is her income and $\overline{x}$ her expenditure in care.

Social welfare is:

$$W^N(\overline{x}) = C_I(\overline{x}) + \sum_{j=1}^{n} C_{V_j}(\overline{x}) =$$

$$i_I - \overline{x} + n i_V - np(\overline{x})\, h - n\tfrac{1}{2}\alpha_V Var(A_j h \mid \overline{x}), \tag{7}$$

where α_V is the average degree of risk aversion of the potential victims:

$$\alpha_V = \frac{\sum_{j=1}^{n} \alpha_j}{n}.$$

Courts set the standard $\overline{x}$ so as to maximize social welfare.

[13] As shown in Appendix A3, the main insights of this paper carry over to the general case.

[14] Households' insurance choices provide information about the size of α. In particular, the following estimates have been obtained: $\alpha \in [0.002, 0.008]$ (Barseghyan et al. (2013) using US data on auto and home insurance), $\alpha \simeq 0.0067$ (Cohen and Einav (2007) using Israeli data on auto insurance), and $\alpha \in [0.002, 0.0053]$ (Sydnor (2010) using US data on home insurance).

Let x_n be the optimal standard: $x_n = \arg\max\left(W^N(\overline{x})\right)$. x_n is assumed to be positive and finite.

Under negligence, the risk is spread across potential victims. Each one bears only his own loss. So, correlation of harms is immaterial.[15]

Strict liability

Under strict liability, the injurer is liable for all of the harm she causes regardless of her level of care. Her total liability expenditure depends on how many people suffer harm, i.e., on $\sum_{j=1}^{n} A_j$. Let $q_k(x)$ be the probability that $\sum_{j=1}^{n} A_j = k$.[16] $q_k(x)$ depends on the level of care x that she decides to take.

The expected utility of the injurer is therefore:

$$EU_I(x) = q_0(x)\, u_I(i_I - x) + q_1(x)\, u_I(i_I - x - h) + \ \dots\ + q_n(x)\, u_I(i_I - x - nh),$$

where i_I is her income and u_I is her utility function.

Again, using an Arrow-Pratt approximation, we get an expression for the payoff of the injurer that depends only on mean and variance of total harm $\sum_{j=1}^{n} A_j h$. Specifically, the certainty equivalent of the injurer is equal to:

$$C_I(x) = i_I - x - np(x)\, h - \tfrac{1}{2}\alpha_I Var\left(\sum_{j=1}^{n} A_j h \mid x\right),$$

where $\alpha_I \geq 0$ is her Index of Absolute Risk Aversion. In view of (4), her certainty equivalent becomes

$$C_I(x) = i_I - x - np(x)\, h - \tfrac{1}{2}\alpha_I\ n\left[1 + (n-1)\,\rho(x)\right] Var\left(A_j h \mid x\right).$$

[15] From a broader perspective, one could argue that correlation matters because it increases the cost of first-party insurance. This can in turn affect the optimal standard (under negligence or safety regulation), which depends on the ability of the victims to bear risk (see Franzoni (2015) for an investigation of the impact of uncertainty aversion on optimal liability law).

[16] Since harms are correlated, this probability cannot be easily calculated. An approximation is provided by Bahadur (1961). If harms are independent of each other, $q_k(x)$ follows the hypergeometric distribution.

If accidents are positively correlated, the liability expenditure of the injurer is subject to great variance, and uncertainty imposes a large cost on her. Conversely, if accidents are negatively correlated, the liability expenditure tends to be concentrated around its mean level, and uncertainty imposes a small cost.

The injurer chooses the level of care x_s that maximizes her payoff: $x_s = \arg\max C_I(x)$. Again, x_s is assumed to be positive and finite.

Victims are perfectly compensated. Hence, the payoff of any individual j is: $C_{V_j}(x_s) = i_V$.

Social welfare under strict liability is:

$$W^S(x_s) = C_I(x_s) + \sum_{j=1}^{n} C_{Vj}(x_s) = \\ i_I - x_s - np(x_s)h - \tfrac{1}{2}\alpha_I n\left[1 + (n-1)\rho(x_s)\right] Var(A_j h \mid x_s) + ni_V. \quad (8)$$

Here, correlation affects the payoff of the injurer and, hence, social welfare. We are now ready to compare liability regimes.

3 Who should bear the loss?

Under negligence, the standard is set by the courts and the loss is borne by the victims. Under strict liability, the level of care is set by the injurer, who also bears the loss. Since the levels of care under the two rules are generally different, a direct comparison of the welfare levels cannot be pursued. I will follow instead an indirect route, as in Franzoni (2015).

Dominance of Negligence. Suppose that courts set a standard of care equal to the level of care chosen by the injurer under strict liability: $\overline{x} = x_s$. In this case, liability rules differ only with respect to the allocation of the loss. From eqs.(7) and (8), we get:

$$\begin{aligned} &W^N(x_s) > W^S(x_s) && \Leftrightarrow \\ &n\tfrac{1}{2}\alpha_V Var(A_j h \mid x_s) < \tfrac{1}{2}\alpha_I n\left[1 + (n-1)\rho(x_s)\right] Var(A_j h \mid x_s) && \Leftrightarrow \\ &\alpha_V < \alpha_I\left[1 + (n-1)\rho(x_s)\right]. \end{aligned}$$

So, if the following condition holds:

$$\text{Condition V:} \quad \alpha_I > \frac{\alpha_V}{1 + (n-1)\,\rho\,(x_s)}, \tag{9}$$

negligence with $\overline{x} = x_s$ is socially superior to strict liability. If courts can optimally set the standard ($\overline{x} = x_n$), social welfare under negligence further increases. Thus, negligence dominates strict liability.

Condition V identifies the potential Victims as the best risk bearers. It is met if potential victims, on average, are weakly averse to risk (small α_V), the injurer is highly averse to risk (large α_I) and harms tend to be positively correlated (large $\rho\,(x_s)$).

Dominance of Strict Liability. Suppose that under strict liability the injurer is forced to take the level of care mandated by the courts under negligence: $x = x_n$. In this case we have

$$\begin{array}{lr} W^S\,(x_n) > W^N\,(x_n) & \Leftrightarrow \\ \frac{1}{2}\alpha_I n\,[1 + (n-1)\,\rho\,(x_n)]\,Var\,(A_j h \mid x_n) < n\frac{1}{2}\alpha_V Var\,(A_j h \mid x_n) & \Leftrightarrow \\ \alpha_V > \alpha_I\,[1 + 1\,(n-1)\,\rho\,(x_n)]\,. & \end{array}$$

If the following condition holds

$$\text{Condition I:} \quad \alpha_I < \frac{\alpha_V}{1 + (n-1)\,\rho\,(x_n)}, \tag{10}$$

strict liability (with a suboptimal level of care) is socially superior to negligence. If we allow the injurer to take the level of care that maximizes her payoff ($x = x_s$), social welfare under strict liability further increases ($C_I\,(x)$ increases while all the $C_{V_j}\,(x)$ are unaffected). So, strict liability dominates. Condition I is the mirror image of Condition V. However, it is evaluated at a different level of care (and hence of correlation).[17]

We have thus proved the following.

Proposition 1 ***Optimal liability rule***

[17] Clearly, *Conditions V* and *I* cannot both hold at the same time. We can have situations, however, in which neither holds. The latter case can arise only when correlation is highly sensitive to the level of care.

a) Negligence dominates strict liability if: $\alpha_I > \dfrac{1}{1+(n-1)\,\rho\,(x_s)}\alpha_V$*.*

b) Strict liability dominates negligence if: $\alpha_I < \dfrac{1}{1+(n-1)\,\rho\,(x_n)}\alpha_V$*.*

Conditions V and I allow us to identify the best risk bearer. They are based on the ability of injurer and potential victims to tolerate risk, and on the structure of risk.

If accidents are uncorrelated, the number of potential victims is irrelevant to the choice of the liability rule. All accidents can be treated as independent cases. Here, only the parties' disposition toward risk matters. The party that is less averse to risk should bear the loss.

When accidents are correlated, the sign of correlation matters: positive correlation shifts the balance toward negligence, negative correlation toward strict liability.[18]

Note that, for the sake of our result, the size of harm h does not matter. The number of potential victims n, instead, serves an important role. The following proposition highlights some important limit cases. It is based on the assumption that both the injurer and the potential victims are risk averse ($\alpha_I > 0$ and $\alpha_V > 0$).

Proposition 2 ***Polar cases***

a) Negligence dominates if harms are positively correlated and the number of potential victims is sufficiently large ($n \to \infty$)*.*

b) Strict liability dominates if the negative correlation between harms is sufficiently strong ($\rho\,(x_n) \to -\frac{1}{n-1}$)*.*

If accidents are positively correlated, $\rho\,(x_s) > 0$, and the number of potential victims is large, Condition V is certainly satisfied: risk spreading through negligence is socially preferable.

Conversely, strict liability dominates when $\rho\,(x_n)$ is strongly negative. In the extreme case in which $\rho\,(x_n) \to -\frac{1}{n-1}$, no uncertainty is attached to the pool of the negatively correlated claims: the injurer faces a loss for sure ($\sum_{i=1}^{n} p\,(x) \to 1$, see eq.

[18] It can be easily shown that Proposition 1 also applies when potential victims take precautionary measures to reduce the probability of harm (bilateral accidents).

5). Non-negligible uncertainty would instead be borne by the victims, if they had to shoulder the loss.

Note that the limit results of Proposition 2 have a general bearing: they extend beyond the mean-variance approach (see Appendix A3).

4 k out of n

So far, no assumption on the shape/nature of correlation has been made. Here, I consider the special case in which exactly k individuals out of n are randomly harmed when an accident occurs. This case captures several scenarios, including transportation of hazardous substances and manufacturing failures, that will be discussed below.

Let the probability that individual j suffers harm be $p(x) = a(x)\frac{k}{n}$, where $a(x)$ is the probability that an accident occurs and $\frac{k}{n}$ the probability that, conditional on an accident, individual j is involved. The correlation between harms is (see Appendix A1):

$$\rho_{k/n}(x) = \frac{\frac{k-1}{n-1} - a(x)\frac{k}{n}}{1 - a(x)\frac{k}{n}}. \tag{11}$$

Note that the correlation index depends positively on k: for $k = 1$, we get $\rho_{1/n}(x) = -\frac{a(x)}{n-a(x)} < 0$; for $k = n$, we get $\rho_{n/n}(x) = 1$.

Note further that, for $k < n$, $\rho_{k/n}(x)$ decreases with $a(x)$: for $a(x) \to 0$, we get $\rho_{k/n}(x) = \frac{k-1}{n-1} \geq 0$; for $a(x) \to 1$, we get $\rho_{k/n}(x) = -\frac{1}{n-1} < 0$. So, when the accident is nearly certain, correlation reaches its lowest bound (eq. (5)).

By plugging eq.(11) in Conditions I and V, we can identify the best risk bearer:

$$\text{Condition V}_{k/n}: \quad \alpha_I > \frac{1 - a(x_s)\frac{k}{n}}{k(1 - a(x_s))}\alpha_V, \tag{12}$$

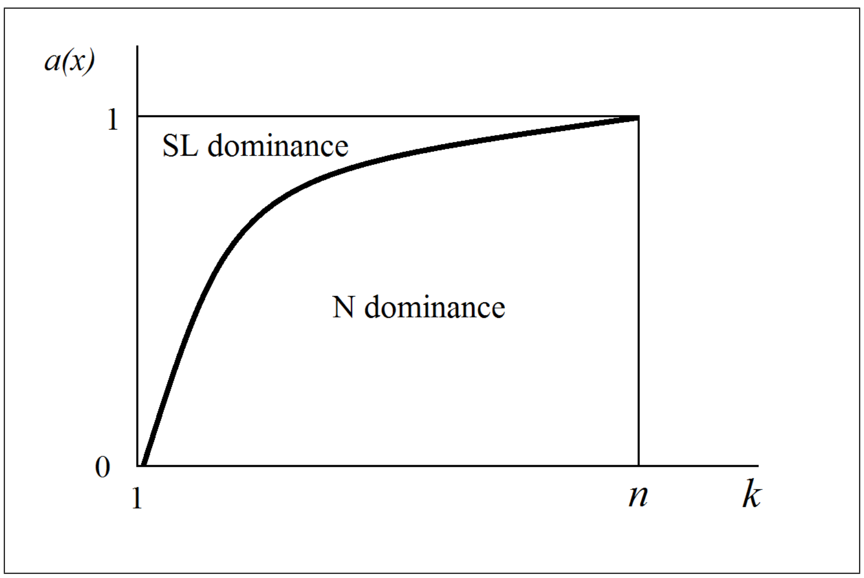
$$\text{Condition I}_{k/n}: \quad \alpha_I < \frac{1 - a(x_n)\frac{k}{n}}{k(1 - a(x_n))}\alpha_V, \tag{13}$$

Again, note that these conditions allow for a comparison of liability rules *given* the equilibrium levels of care x_s and x_n. We have thus proved the following:

Proposition 3 *Let $\alpha_I > 0$ and $\alpha_V > 0$ and assume that exactly k victims out of n suffer harm when an accident occurs. When k is small and the probability of an accident under negligence is large, strict liability dominates. When k is large and the probability of an accident under strict liability is small, negligence dominates.*

Note that when $k < n$ and the accident is nearly certain under negligence, Condition $\mathrm{I}_{k/n}$ is met for sure: strict liability is the preferable liability rule. No uncertainty is borne by the liable injurer (she bears a loss equal to kn). Uncertainty would be borne by the potential victims, instead, if negligence were in place (they suffer harm with probability k/n).

Fig. 1 illustrates the dominance areas for the case in which the injurer and 10 potential victims are equally averse to risk: $\alpha_I = \alpha_V$. Given k, if $a(x_n)$ falls in the SL area, then a switch from negligence to strict liability increases welfare. If $a(x_s)$ falls in the N area, a switch from strict liability to negligence increases welfare.



k victims out of n ($n = 10$).

The k/n case captures several interesting scenarios. The first concerns the transportation of hazardous substances. When moving from A to B, the carrier crosses areas with (roughly) the same population density. So, in the case of an accident, the number of victims will most likely be k. The total number of people who could potentially be affected (along the route) is n. In this context, strict liability is preferable when the probability of an accident is very high, i.e., when the activity is "abnormally dangerous." The loss is nearly certain for the injurer under strict liability, while it is uncertain for the bystanders under negligence.

A second application of the k/n model is the case of a manufacturing process for which the fraction of defective items, in the case of failure, can be predicted with a good degree of accuracy. If the probability of failure, $a(x)$, is very high, then strict liability tends to dominate (accidents are negatively correlated). More specifically, however, let us consider the case in which the probability of failure is not extreme. Here, which liability rule is more efficient depends (among the other factors) on the level of k. A small k shifts the balance toward strict liability, a large k toward negligence. As noted in the introduction, this proposition resonates with current products liability law, which subjects manufacturing defects to strict liability and design defects (which are most likely to affect the whole product line) to negligence.

The case of products liability in explored in greater detail in Appendix A2, where I consider a perfectly competitive market in which firms invest in the safety of their products. Depending on whether harms are positively or negatively correlated, the harm structure produces diseconomies or economies of scale, respectively. I show that Propositions 1 and 2 carry over to this extended set-up. The correct allocation of risk increases social surplus and benefits both producers and consumers.

Remark. Clearly, the harm structure matters insofar as parties care about the variance of their payoffs, or, more specifically in this model, insofar as parties are averse to risk. One may wonder what the actual degree of risk aversion of producers might be. If producers are closely held firms, private firms or partnerships, then risk aversion follows directly from the risk aversion of the owners/partners, on the assumption that owners/partners do not have a fully diversified investment portfolio.

For publicly held corporations with dispersed ownership, risk neutrality tends to be presumed. The idea is that small shareholders have fully diversified portfolios and only care about the mean return of their investments. Yet, if this were true, we would not observe companies engaging in risk management practices, as we actually do. Thus, it appears that public companies also often behave like risk-averse agents and try and contain the volatility of their balance sheets. Several explanations for this fact have been provided, including the cost of bankruptcy (which leads firms to avoid very adverse outcomes), the cost of external funds (which might be needed in adverse states), asymmetric information (the firm's behavior reflects the risk aversion of directors and managers whose remuneration depends on the firm's performance), a convex tax schedule, and debt overhang (the underinvestment caused by debt can be reduced if risks are managed).[19]

Finally, once risk aversion on the side of the firms is established, one may wonder if the availability of insurance might completely neutralize it. The next section shows that this is not the case.

5 Costly insurance

Insurance against liability claims for bodily injury and property damage arising out of premises, products, and completed operations is usually available to business organizations, under so called CGL policy. Insurance often comes together with "loss control" provisions, aimed at reducing liability risk (Baker and Siegelman (2013)). In what follows, I extend the model to the case in which parties can purchase insurance on the market. The important point here is that I assume, in line with current industry practice, that insurance comes with a positive loading factor, covering the management and operational costs of the insurers.[20] For this reason, the optimal insurance policy

[19]See, for instance, Froot et al. (1993), and Bernard (2013). See also the insightful discussion of Nell and Richter (2003). Quite aptly, the *Restatement (Third) of Torts: Liability for Physical and Emotional Harm* (2010) does not presume that firms are by default the best risk bearers. In comment *e)* to § 20, the ALI reporters point out that "The appeal of strict liability [for abnormally dangerous activities,] [...] does not depend on any notion that the defendant is in a better position than the plaintiff to allocate or distribute the risk of harm; indeed, the defendant may be a small business enterprise, the property damage suffered by the plaintiff may be no more than moderate, and the plaintiff as a property owner may already be insured for the loss that that damage entails." The identification of the best risk bearer must be context-dependent.

[20]Administrative costs (excluding risk loading and loss adjustment expenses) generally amount to 30-50% of premiums (see Harrington and Niehaus (2003), p. 146). Incidentally, note that correlation

will entail a deductible, as commonly observed in practice (see Ambrose et al. (2013)). For simplicity, potential victims are assumed to be all equally averse to risk (so they will all chose the same deductible).

Under strict liability (third-party) insurance is purchased by the injurer. The insurer can observe the level of care taken by the injurer. Under negligence, (first-party) insurance is purchased by the victims.

Negligence. Under negligence, the loss falls on the victims (assuming, again, that the injurer meets the standard of care x_n). Potential victims can purchase first party insurance at a premium w_V. The insurance contract specifies a deductible d_V. The insurance premium is thus $w_V = p(x_n)(h - d_V)(1 + \lambda)$, where $\lambda > 0$ is the loading factor. Individuals choose the deductible so as to maximize

$$\begin{aligned} C_V(x_n) &= i_V - p(x_n) d_V - \tfrac{1}{2}\alpha_V Var(A_j \mid x_n) d_V^2 - (p(x_n)(h - d_V)(1+\lambda)) = \\ &= i_V - p(x_n)(h + \lambda(h - d_V)) - \tfrac{1}{2}\alpha_V Var(A_j \mid x_n) d_V^2. \end{aligned}$$

The optimal deductible is therefore

$$d_V^* = \begin{cases} \frac{\lambda p(x_n)}{\alpha_V Var(A_j|x_n)} & \text{if } \frac{\lambda p(x_n)}{\alpha_V Var(A_j|x_n)} < h \\ h & \text{otherwise.} \end{cases}$$

Social welfare now is:

$$\begin{aligned} W^N(x_n) &= C_I(x_n) + nC_V(x_n) \\ &= i_I - x_n + ni_V - p(x_n) n (h + \lambda(h - d_V^*)) - \tfrac{1}{2} n\alpha_V Var(A_j \mid x_n) d_V^{*2}. \quad (14) \end{aligned}$$

The optimal standard x_n^* maximizes $W^N(x_n)$.

Strict liability. The injurer purchases liability insurance from the market. The insurer observes the level of care x_s taken by the injurer and charges a premium $w_I =$

typically affects the risk loading component.

$n\ p(x_s)(h - d_I)(1+\lambda)$, where d_I is the deductible chosen by the injurer. We have

$$\begin{aligned} C_I(x) &= i_I - x - np(x)\, d_I - \tfrac{1}{2}\alpha_I n\left[1 + (n-1)\rho(x_s)\right] Var(A_j \mid x)\, d_I^2 - np(x_s)(h - d_I)(1+\lambda) \\ &= i_I - x - np(x)\left[h + \lambda(h - d_I)\right] - \tfrac{1}{2}\alpha_I n\left[1 + (n-1)\rho(x_s)\right] Var(A_j \mid x_s)\, d_I^2. \end{aligned}$$

The optimal deductible is therefore:

$$d_I^* = \begin{cases} \frac{\lambda p(x_n)}{\alpha_I[1+(n-1)\rho(x_s)]Var(A_j|x_s)} & \text{if } \frac{\lambda p(x_n)}{\alpha_I[1+(n-1)\rho(x_s)]Var(A_j|x_s)} < h \\ h & \text{otherwise.} \end{cases}$$

Ceteris paribus, the deductible is smaller is harms are positively correlated.

Social welfare now is:

$$\begin{aligned} W^S(x_s) &= C_I(x_s) + nC_V(x_s) = \\ & i_I - x_s - np(x_s)\left[h + \lambda(h - d_I^*)\right] - \tfrac{1}{2}\alpha_I n\left[1 + (n-1)\rho(x_s)\right] Var(A_j \mid x_s)\, d_I^{*2} + ni_V. \end{aligned} \tag{15}$$

The optimal level of care x_s^*, together with the optimal deductible, d_I^*, maximizes $W^S(x_s)$.

We can now compare the welfare levels under the two liability rules.

Dominance of Negligence. Suppose that courts set a standard of care equal to the level of care chosen by the injurer under strict liability: $\overline{x} = x_s$ and that potential victims are forced to chose a deductible d_V equal to the level of the deductible d_I^* chosen by the injurer under strict liability. Under these conditions, negligence dominates if, and only if (from 14 and 15):

$$\alpha_I < \frac{\alpha_V}{1 + (n-1)\rho(x_s)},$$

i.e., if and only if Condition V holds.

If potential victims can chose the level of the deductible they prefer, their payoff increases, while the payoff of the injurer remains unaffected. Thus social welfare under negligence increases. If courts can change the standard of care and set it at x_n^*, welfare further increases. So negligence dominates strict liability.

Dominance of Strict Liability. Suppose that the injurer is forced to set $x = x_n$ and to fix the deductible at the level that would be chosen by the potential victims under negligence, $d_I = d_V^*$. Under these conditions strict liability dominates if and only if

$$\alpha_I > \frac{\alpha_V}{1 + (n-1)\,\rho\,(x_n)},$$

i.e., if Condition I holds.

If the injurer is allowed to freely chose the level of care and the level of the deductible, her payoff increases, while the payoff of the victims is unaffected. Social welfare under strict liability increases. So, if Condition I holds, strict liability dominates negligence. We have thus proved the following.[21]

Proposition 4 ***Insurance***

Given a positive loading factor,

a) negligence dominates strict liability if: $\alpha_I > \dfrac{1}{1 + (n-1)\,\rho\,(x_s)}\alpha_V$.

b) strict liability dominates negligence if: $\alpha_I < \dfrac{1}{1 + (n-1)\,\rho\,(x_n)}\alpha_V$.

Note that for the comparison of liability rules, the shape of the insurance costs is immaterial. The proof of Proposition 4 is only based on the assumption that, if we shift the insurance coverage from one side to the other leaving the harm structure unaltered, insurance costs do not change.

6 Conclusion

This paper highlights an important dimension relevant to the choice between liability rules, which pertains to the statistical structure of harm and the ability of the parties to bear risk.

Positively correlated harms commend a liability rule that spreads risks; negatively correlated harms a liability rule that pools risks together. Design defects and warning

[21] Note that for the comparison of liability rules, the shape of insurance costs is immaterial. The proof of the latter result is based on the idea that if we shift the insurance coverage from one side to the other, leaving the harm structure unaltered, insurance costs do not change.

failures, for instance, generate strongly positively correlated harms, and thus favor a negligence rule. The same cannot be said about manufacturing defects, which tend to produce weakly correlated harms (and, possibly, negatively correlated harms). In this case, the loss should be allocated primarily on the basis of the disposition of the parties toward risk. Here, one might conjecture that producers, especially publicly held corporations with dispersed ownership, have a comparative advantage in handling risk. If this is true, then strict liability should apply.

The results of this paper are very general: they apply to all the myriad subfields in the law of torts. In the clearest instances where the structure of the risk of harm is correlative - design defects and warning failures, for example - it explains the underlying economic rationale for the state of the law. In other instances where correlation is more subtle, and where the law is yet insensitive to the structure of risks, these insights could be used to improve existing laws.

Appendix

A1. *k out of n*

Let the probability that individual j suffers harm be $pr\left(A_j = 1\right) = a\left(x\right)\frac{k}{n}$, where $a\left(x\right)$ is the probability that an accident occurs and $\frac{k}{n}$ the probability that individual j is involved. The probability that individual k suffers harm, given that victim j suffers harm, is $pr\left(A_k = 1 \mid A_j = 1\right)$ $= \frac{k-1}{n-1} \times a\left(x\right)\frac{k}{n}$.

The covariance between A_j and A_k is therefore

$$\begin{aligned} Cov\left(A_j, A_k \mid x\right) &= E(A_j A_k \mid x) - E(A_j \mid x)E(A_k \mid x) \\ &= \frac{k\left(k-1\right)}{n\left(n-1\right)}a\left(x\right) - \left(a\left(x\right)\frac{k}{n}\right)^2 = a\left(x\right)\ \frac{k}{n}\left[\frac{k-1}{n-1} - a\left(x\right)\frac{k}{n}\right], \end{aligned}$$

while the correlation coefficient is

$$\begin{aligned} \rho_{k/n}\left(x\right) &= \frac{Cov\left(A_j, A_k \mid x\right)}{\sqrt{Var\left(A_j \mid x\right)Var\left(A_k \mid x\right)}} = \frac{a\left(x\right)\ \frac{k}{n}\left[\frac{k-1}{n-1} - a\left(x\right)\frac{k}{n}\right]}{a\left(x\right)\frac{k}{n}\left(1 - a\left(x\right)\frac{k}{n}\right)} \\ &= \frac{\frac{k-1}{n-1} - a\left(x\right)\frac{k}{n}}{1 - a\left(x\right)\frac{k}{n}}. \end{aligned} \tag{16}$$

This is the formula used in Section 4.

A2. Products liability

In this Section, I show how the analysis extends to the case in which harm is caused by products sold in a competitive market. For simplicity, I assume that each consumer purchases only one unit of the product. A_j takes the value 1 if a generic unit j is defective and causes harm h. Let x be the expenditure in safety per unit of product. The safety level is not observable by the consumers.[22] Producers are all identical. Let $Q_D\left(P\right)$ represent the number of units demanded, given the price P.

[22] For simplicity, I do not consider more sophisticated policies available to producers, including signaling through prices, third-party certification, warranties, recalls, and ex-post warnings. See the thorough survey of Daughety and Reinganum (2013a). I also exclude the possibility that consumers and firms opt out of the liability system once the investment in safety is sunk (a case studied by Wickelgren (2006)).

Let us consider *strict liability* first. Given the market price m, total consumer surplus is

$$CS\left(Q^{D}\left(m\right)\right)=\int_{0}^{Q^{D}\left(m\right)}\left[Q_{D}^{-1}\left(z\right)-m\right]dz.$$

The payoff of the representative producer (Π) is affected negatively by the volatility of profits, $\pi\left(x,Q\right)$. So

$$\begin{aligned}\Pi &= E\left(\pi\left(x,Q\right)\right)-\frac{1}{2}\alpha_{I}Var\left(\pi\left(x,Q\right)\right)\\ &= mQ-F-Q\left[c+x_{s}+p\left(x_{s}\right)h\right]-\tfrac{1}{2}\alpha_{I}Q\left[1+\left(Q-1\right)\rho\left(x_{s}\right)\right]Var\left(A_{j}h\mid x_{s}\right),\end{aligned}$$

where mQ is the revenue, F the fixed cost, c the marginal cost, x_s the per-unit safety expenditure, $p\left(x_s\right)h$ the per-unit expected liability, and $Q\left[1+\left(Q-1\right)\rho\left(x_s\right)\right]\ Var\left(A_jh\mid x_s\right)$ the variance of the liability expenditure. $\rho\left(x_s\right)$ is the average correlation across defects .If the number of defective items can be estimated with good accuracy, then the k/n model applies and $\rho\left(x\right)=\rho_{k/n}\left(x\right)$.

Given the market price m, the producer sets Q and x so that

$$\begin{cases}\Pi_{Q}'= & m-c-x-p\left(x\right)h-\tfrac{1}{2}\left[1+\left(2Q-1\right)\rho\left(x_{s}\right)\right]\alpha_{I}Var\left(A_{j}h\mid x_{s}\right) & =0\\ \Pi_{x}'= & -Q\left(1+p'\left(x\right)d+\tfrac{1}{2}\alpha_{I}\frac{\partial\left[1+\left(Q-1\right)\rho\left(x_{s}\right)\right]Var\left(A_{j}h\mid x_{s}\right)}{\partial x}\right) & =0.\end{cases}$$

Note that $\frac{\partial\Pi_{Q}'}{\partial Q}=-\rho\left(x_{s}\right)\ \alpha_{I}Var\left(A_{j}h\mid x_{s}\right)$. Depending on whether harms are positively or negatively correlated, the harm structure produces diseconomies or economies of scale, respectively.[23]

Total surplus is

$$\begin{aligned}&W^{s}\left(Q,x\right)=CS\left(Q\right)+\Pi=\textstyle\int_{0}^{Q}\left[Q_{D}^{-1}\left(z\right)\right]dz\\ &-F-Q\left\{c+x_{s}+p\left(x_{s}\right)h+\tfrac{1}{2}\left[1+\left(Q-1\right)\rho\left(x_{s}\right)\right]\alpha_{I}Var\left(A_{j}h\mid x_{s}\right)\right\}.\end{aligned}$$

At the market equilibrium, the quantity Q^s maximizes surplus given x_s, while x_s is set by the

[23] Since safety and quantity are interdependent, the standard separability between market structure and safety performance fails to apply. In this paper, I do not address the issue of the "resilience" of liability rules to changes in market performance (see Daughety and Reinganum (2013b) and Daughety and Reinganum (2014)).

producer so as to maximize her payoff given the market price and, thus, the quantity. Since consumers cannot directly observe x_s, variations in safety do not command changes in market prices (see Shavell (1980)). Thus, the market outcome is characterized by

$$\begin{cases} Q_D^{-1}(Q^s) - c - x_s - p(x_s)h - \frac{1}{2}[1 + (2Q^s - 1)\rho(x_s)]\alpha_I Var(A_j h \mid x_s) = 0, \\ 1 + p'(x_s)d + \frac{1}{2}\alpha_I \frac{\partial[1+(Q^s-1)\rho(x_s)]Var(A_j h|x_s)}{\partial x} = 0. \end{cases} \tag{17}$$

Under *negligence*, producers meet the standard $\overline{x}$ so as to avoid liability. Again, a greater level of safety would not be recognized by the consumers and, hence, does not pay off. Total surplus is

$$W^n(Q, \overline{x}) = \int_0^Q \left[Q_D^{-1}(z)\right] dz - Q\left[c + \overline{x} + p(\overline{x})h + \tfrac{1}{2}\alpha_V Var(A_j h \mid \overline{x})\right],$$

where $\frac{1}{2}\alpha_V Var(A_j h \mid \overline{x})$ is the average uncertainty cost shouldered by the consumers.

Courts set $\overline{x} = x^n$, while the market sets Q^n so that $\frac{\partial W^n(Q^n,\, x^n)}{\partial Q} = 0$ given x^n. The optimal standard solves

$$1 + p'(x^n)h + \frac{1}{2}\frac{\partial \alpha_V Var(A_j h \mid x^n)}{\partial x} = 0 \tag{18}$$

(thanks to the Envelope theorem, the impact of x on Q^n can be disregarded).

Let us compare negligence and strict liability. Suppose that under negligence the courts sets $\overline{x} = x^s$. Negligence dominates if the following condition holds:

$$\text{Condition } V^P: \qquad \alpha_I > \frac{\alpha_V}{1 + (Q^s - 1)\rho(x_s)}.$$

Total surplus further increases if the court can freely set $\overline{x} = x^n$.

Reverse. If the producer were forced to set $x = x^n$, strict liability would dominate under the following condition:

$$\text{Condition } I^P: \qquad \alpha_I < \frac{\alpha_V}{1 + (Q^n - 1)\rho(x^n)}.$$

If the producer is allowed to set $x = x^s$, costs decrease and total surplus under strict liability further increases (consumers can purchase additional units).

Conditions $V^P$and I^Pidentify in a clear cut way the best risk bearers. Producers are the best risk bearers if they are less averse to risk than the consumers and/or if defects are negatively correlated. Consumers are the best bearers if they have a lower degree of risk aversion and/or if defects are positively correlated. If the fraction of defective items can be predicted with accuracy, then the k/n model applies. Strict liability is marginally preferable when k is small and the probability that a defective item causes harm under negligence, $a(x_n)$, is large; negligence is preferable when k is large and the probability that a defective item causes harm under strict liability, $a(x_s)$, is small.

A3. *Generality of results* The results of this paper extend beyond the mean-variance model. Let us consider the case in which correlation is positive and the number of potential victims is large. Here, strict liability imposes a risk with infinite variance (and skewness) on the injurer, while negligence (under the level of care arising under strict liability) imposes risk with bounded variance on the victims. So, negligence dominates as far as utility functions are strictly concave, independently of the income levels of the parties. Conversely, if harms are strongly negatively correlated, strict liability imposes a risk with negligible variance on the injurer, while negligence imposes risk with substantial variance on the victims. So strict liability dominates, as far as utility functions are strictly concave.

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