The joint use of regulation and strict liability with multidimensional care and uncertain conviction

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A B S T R A C T

The purpose of this paper is to explore the joint use of regulation and strict liability when firms can take care in both observable and unobservable dimensions and when the firm's conviction for damages is uncertain. Much of the literature concerning joint use regards management of the judgment-proof problem; the take-home result of our paper is that if the harming party can take both observable and unobservable care, then joint use can improve welfare even in the absence of judgment-proofness. This is true even when penalty multipliers are allowed, provided social welfare is negatively related to the firm's expected liability costs. In fact, use of penalty multipliers further strengthens the case for joint use.

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1. Introduction

The purpose of this paper is to explore the joint use of regulation and strict liability when firms can take care in both observable and unobservable dimensions and when the firm's conviction for damages is uncertain. We are motivated to explore this topic because, on one hand, this set of factors is present in most activities that carry a risk of an accident, while on the other hand, so little has been written regarding the nuances of joint use and of multidimensional care. The policy arenas of municipal solid waste, hazardous materials, nuclear materials, pesticide usage, food safety, and product safety all exhibit significant joint use of state/federal regulation and some type of tort law mechanism (strict liability, negligence rule, joint-and-several liability, or extended liability); both observable and unobservable care strategies; and uncertainty over the likelihood of conviction. For instance, oil facilities have to abide by many rules and regulations (described in the US EPA Spill Prevention, Control and Countermeasures (SPCC) in 40 CFR 112) and are also liable for any clean-up costs and damages resulting from oil spills under the Oil Pollution Act of 1990. An example of observable care in this case is the use of approved equipment and provision of appropriate containment or diversionary structures. Unobservable care regards the more or less careful attention with which personnel operate this equipment and perform tasks of inspection. In the context of nuclear power production, as Trebilcock and Winter (1997) point out, the Price–Anderson Act imposes strict liability in addition to a wide range of plant-level regulations promulgated by the Nuclear Regulatory Commission. Some of the care plant operators can take is observable—such as the installation of certain filters and following certain procedures. However, the careful attention the labor gives to daily operations is not observable, and therefore cannot be regulated.

Multiple scholars (e.g. Shavell, 1984; Kolstad, Ulen, & Johnson, 1990; Burrows, 1999; Schmitz, 2000; Innes, 2004) have discussed theoretical properties of joint use. Much of the literature concerning joint use (e.g. Shavell, 1984; Schmitz, 2000; De Geest & Dari-Mattiacci, 2007) regards management of the judgment-proof problem (in which a firm may not have verifiable resources to pay for the damage it causes) as its main purpose. For example, Shavell (1984) shows that when there is conviction uncertainty, heterogenous harm levels, judgment-proofness, and penalty multipliers are not allowed, then joint use can be superior to individual employment of regulation or strict liability. Schmitz (2000) shows, however, that if one allows for penalty multipliers, then in addition to the other features in Shavell's (1984) model, one also needs wealth differences for joint use to be superior. De Geest and Dari-Mattiacci (2007) suggest that when liability alone fails to induce optimal care due to judgment-proofness of the firms, then supplementing it with regulation can help, since the latter enforces some minimal care that reduces the extent of harm below the firm's resources and thereby removes the judgment-proofness problem. Notwithstanding the importance of these results, as Innes (2004) observes, many of the above environments such as waste management and food safety feature large, relatively wealthy firms that are not obviously in danger of being found judgment-proof. We
agree with Innes that on efficiency grounds we need more than the threat of judgment-proofness to motivate the degree of regulation and strict liability that we so often observe. Innes (2004) argues that one possible reason for the high degree of joint use that we observe is that regulators often monitor and enforce both the firm’s care and occurrence of an accident. He shows that depending upon the degree of these enforcement costs, it can be efficient to complement liability with regulation. However, compared to our paper, the important difference in Innes (2004) is that both are not jointly used on any given firm. In Innes’ model if a firm’s care is monitored and it is found to have complied with the standard then no liability is imposed on it in the event of an accident. We show as in Shavell (1984) and Schmitz (2000) that joint use of both regulation and strict liability on the same firm may be desirable, but without the standard motivating factors of heterogeneous harm levels, judgment-proofness or wealth differences. Innes (2004). In this case, regulating the observable dimension can improve the firm’s care not only in the observable dimension but also in the unobservable dimension.

When penalty multipliers are allowed (Section 4) then ex post liability alone induces socially optimal care; however, it does so with a higher expected liability cost than can be achieved with joint use. When increased costs of doing business can adversely affect welfare then the fact that joint use can induce socially optimal care with lower expected liability costs makes it desirable even when penalty multipliers are allowed. Lastly, we note that penalty multipliers mitigate the problem of conviction uncertainty. Hence, by adding multidimensional care and penalty multipliers that are not restricted to be greater than one to Shavell’s (1984) model, we are able to show that joint use can be superior to regulation or strict liability alone in the absence of both the judgment-proofness assumption and the conviction uncertainty assumption.

We are not the first to propose that optimal regulatory strategy must take into account the agent’s multiple dimensions of care. We are preceded in this literature by Bartsch (1997), Trebilcock and Winter (1997), and most recently, Hutchinson and van’t Veld (2005). Bartsch (1997) considers implications of multidimensional care for the stringency of negligence standards, but she does not consider joint use of regulation and liability. Trebilcock and Winter (1997) take regulation as given but do not explain why regulation is required if strict liability is available; strict liability alone would be sufficient in their model. And Hutchinson and van’t Veld (2005) assume judgment-proofness and focus upon extended liability when there is multidimensional care.

Our paper proceeds as follows. In Section 2, we construct our basic model in which social optimality requires the firm to take care in both observable and unobservable dimensions. In Section 3, we compare the alternative rules in the absence of penalty multipliers. In Section 4 we discuss the role of joint use when penalty multipliers are allowed. We offer some concluding remarks in Section 5. The proofs are presented in the Appendix.

2. The model

Consider a risk-neutral monopolist engaged in an activity that carries with it a risk of an accident. While the product is useful it is possible that it may fail and harm the consumers and/or third parties. Let \( p \) denote the likelihood of accident and \( D \) the extent of damages per unit produced. The firm can reduce \( p \) and/or \( D \) by exercising care in two dimensions, say \( e_o \) and \( e_u \), where \( e_o \) is observable and \( e_u \) is unobservable to outsiders. For example, a firm that manages hazardous waste can employ new, observable physical capital around the perimeter of its facility and also apply more effort to self-audit its operating procedures. For simplicity, assume that the care decision in each dimension is binary, i.e. the firm either exercises care or does not exercise care in dimension \( i (i = o, u) \).

If the firm exercises care in dimension \( i \) then \( e_i = 1 \); otherwise, \( e_i = 0 \). Let us denote by \( H(e_o, e_u) = p(e_o, e_u)D(e_o, e_u) \), the expected harm per unit, which depends on the care exercised. Further, let \( \psi_i \) denote the cost incurred per unit due to care in dimension \( j \) (where \( j \in \{o,u\} \)), and let \( c(e_o, e_u) \) denote the total cost per unit produced. Then, \( c(0,0) = 0, c(1,0) = \psi_o, c(0,1) = \psi_u, \) and finally \( c(1,1) = \psi_o + \psi_u \). Using these the social marginal cost of production is \( H(e_o, e_u) + c(e_o, e_u) \), the sum of the expected harm and the total cost of care per unit. We make the following assumptions:

**A.1.** \( H(0,0) > H(0,1) = H(1,0) \).

**A.2.** \( H(1,0) + \psi_o < H(0,0) \) and \( H(0,1) + \psi_u < H(0,0) \).

**A.3.** Social marginal cost is minimized when care is exercised in both dimensions, i.e. when \( (e_o, e_u) = (1,1) \).

Assumption (A.1) implies that expected harm decreases with care in either dimension, and by themselves, care in the two dimensions are equivalent. (A.2) says that social marginal cost is lower when care is exercised in a single dimension than when it is not exercised in any dimension. Assumption (A.3) requires that (i) \( H(0,0) > H(1,1) + \psi_o + \psi_u \), (ii) \( H(0,1) + \psi_o > H(1,1) + \psi_o + \psi_u \) and, (iii) \( H(1,0) + \psi_u > H(1,1) + \psi_u + \psi_o \). If \( \psi_o \geq \psi_u \) then condition (iii) is implied by condition (ii). If \( \psi_o \geq \psi_u \) then condition (iii) implies (ii).

The firm’s full marginal cost of production is the sum of the total cost of care per unit, \( c(e_o, e_u) \), and the expected penalty that it has to pay per unit. Denoting the latter by \( f(e_o, e_u) \), we can write the firm’s full marginal cost of production as \( c(e_o, e_u) + f(e_o, e_u) \). In addition to the level of care, \( c(e_o, e_u) \) also depends on the details of the liability rule and the likelihood of conviction. For example, if there is no liability then \( f(e_o, e_u) \) is zero. If the firm is responsible for damages, the penalty multiplier is \( m \) and the likelihood of conviction is \( q \), then \( f(e_o, e_u) = mqH(e_o, e_u) \). The exact form of \( f(e_o, e_u) \) is specified below when different rules are discussed.

On the consumer side of the economy let us suppose, as in Bhole (2007), that there are two types of consumers who differ in their willingness-to-pay for the firm’s product—those willing-to-pay \( \theta_h \), who are called high-value (or high-type) consumers; and those willing-to-pay \( \theta_l < \theta_h \), who are called low-value (or low-type) consumers. Out of a total of \( N \) consumers, suppose a fraction \( \alpha \) are of type \( \theta_h \) and a fraction \( 1 - \alpha \) are of type \( \theta_l \). While \( \alpha \) is known to the firm, it cannot distinguish between the

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2 We have in mind settings in which the firm sells products to consumers and the firm’s liability costs affect the prices and quantities that consumers face. Consumers may or may not be the potential victims. It is possible that the product failure harms third parties as in the case of environmental harms.

3 The assumption that the observable care and the unobservable care are equally effective is made only to simplify the exposition. Many different cases need to be considered if this assumption is relaxed, which lengthens the exposition without adding much. Our basic result that joint use can do strictly better than both strict liability alone and regulation alone goes through in most of the cases that arise when the assumption of equal effectiveness is relaxed. Also, as here, we find that when efforts are complementary joint use is never inferior to either regulation alone or strict liability alone.
two types of consumers. We also assume that each consumer consumes at most one unit. These assumptions imply that the firm has to charge a uniform price, say $p$, to all consumers. It can either charge $\theta_h$ and serve only the high-value consumers, or charge $\theta_l$ and serve all consumers.\(^4\) If $P = \theta_l$ the firm’s profit is $\pi(e_o, e_u) = [\theta_l - c(e_o, e_u) - f(e_o, e_u)]$ and with $P = \theta_h$ its profit is $\pi(e_o, e_u) = \alpha N[\theta_h - c(e_o, e_u) - f(e_o, e_u)]$. Hence, the firm will charge a lower price and serve all the consumers only if $\theta_l \leq (\theta_l - c(e_o, e_u) - f(e_o, e_u))/[\theta_h - c(e_o, e_u) - f(e_o, e_u)]$; otherwise it will charge $\theta_h$.\(^5\) Note that $[\theta_l - c(e_o, e_u) - f(e_o, e_u)}/[\theta_h - c(e_o, e_u) - f(e_o, e_u)]$ is a decreasing function of $c(e_o, e_u)$ and $f(e_o, e_u)$, implying that the greater the firm’s full marginal cost of production, the greater is the range of values for which the firm charges a high price, i.e. the greater is the likelihood that the firm will shut out the low valuation consumers.\(^6\) Note also that regardless of whether the firm charges $\theta_h$ or $\theta_l$ it maximizes its profit when it chooses $(e_o, e_u)$ to minimize its full marginal cost $c(e_o, e_u) + f(e_o, e_u)$.

The gross benefit to society from any unit produced – as measured by the consumer’s willingness-to-pay – is $\pi(u)$. It can be shown that all our qualitative conclusions go through even if $\pi(u)$ is a decreasing function of $\pi(u)$ and serves only the high-valuation consumers, or

\[\theta_l < H(0, 1) + \psi_o, \quad \theta_h < H(0, 1) + \psi_o, \text{and} \quad \theta_l > H(1, 1) + \psi_o + \psi_u.\]

Along with (A.2) this assumption implies that consumption by low-value consumers is socially desirable if and only if the care is exercised in both dimensions. Assumption (A.4) along with Assumption (A.3) guarantees that socially optimal care is one in both dimensions (i.e. $(e_o, e_u) = (1, 1)$).

In the above described setting we compare the three alternatives of regulation alone, a strict liability rule alone and the joint use of regulation and strict liability to see whether and when joint use can improve upon the former two. Since the setup assumes binary care, the regulatory standard in any dimension has to be either ‘care’ or ‘no care’. We refer to the former as “regulation” and the latter as “absence of regulation” in that dimension (rather than calling it regulation with standard set at ‘no care’). Similarly, joint use assumes a regulatory standard of “care” along with strict liability (a regulatory standard of “no care” along with strict liability is same as the rule of strict liability alone).

3. Joint use in the absence of penalty multipliers

It is easier to compare the alternative rules if we separate the cases in which efforts are complements and substitutes. We say $e_o$ and $e_u$ are complements, if

\[H(0, 1) - H(1, 1) > H(0, 0) - H(1, 0) \quad \text{and} \quad H(1, 0) - H(1, 1) > H(0, 0) - H(0, 1)\]

and substitutes if,

\[H(0, 1) - H(1, 1) < H(0, 0) - H(1, 0) \quad \text{and} \quad H(1, 0) - H(1, 1) < H(0, 0) - H(0, 1)\]

That is, they are complements (substitutes) if the marginal decrease in expected harm caused by care in any dimension is greater (smaller) when care is also exercised in the other dimension. For an example of care as complements consider the EPA’s SPCC rules and regulations that require on-shore oil facilities to use open-and-close design valves (as opposed to flapper-type drain valves) to prevent discharge of oil from diked storage areas. These rules also require appropriate personnel to inspect these storage areas for oil contamination before the stormwater is drained out.\(^8\) We would argue that open-and-close valves are likely to be less effective (resp. more effective) in preventing accidental oil discharge if personnel are not careful (resp. more careful) about testing for contamination before they open such valves for drainage. If such valves reduce expected harm by, say, $\delta X$ if personnel are not very careful, they will reduce it by more than $\delta X$ if the personnel are very careful.

In contrast, consider an example of care as substitutes. SPCC regulations require on-shore facilities to provide appropriate secondary containment structures such as dikes, berms or retaining walls capable of containing oil so that a discharge from the primary containment system (such as a tank or a pipe) does not escape out of the facility before clean-up can occur.\(^9\) It seems that measures aimed at preventing accidental discharge from the primary containment system will be effective, but less so in reducing harm to the environment when such secondary containment is available. Say, for example, if care by personnel with the primary containment reduces expected harm by $\delta Y$ when there is no secondary containment, such care will reduce expected harm by less than $\delta Y$ when there is secondary containment.

Given Assumption (A.1) we can simplify the notation by defining $H_0 = H(0, 0); H_1 = H(0, 1) = H(1, 0); H_2 = H(1, 1)$.

3.1. When efforts are complements

3.1.1. Regulation only

Since $e_u$ is unobservable, it cannot be regulated. With the absence of any liability and absence of regulation in dimension $e_u$, the firm has no incentive to exercise unobservable care, i.e. $e_u^* = 0$. With regulation in the observable dimension, the firm exercises

\(^4\) If the harm due to product failure is inflicted on third parties (as is true in case of many environmental accidents) then consumers’ willingness-to-pay can be assumed to be independent of their expectations about the care level. If, however, the harm is inflicted on consumers then their willingness-to-pay may depend on the expected care level. This expectation can be based on past experiences with the firm (their own or those of others) and on information about the liability rule (for example, the size of the multiplier). We assume for simplicity that at the time of purchase, consumers do not take account of the liability rule and therefore it does not influence $\theta_h$ and $\theta_l$. It can be shown that all our qualitative conclusions go through even if consumers take account of the liability rule in forming expectations about the firm’s care and payments that they would receive in the event of an accident, provided some fraction of the penalty imposed on the firm is not received by consumers—for example, lawyers get a fraction of the award when cases are fought on a contingency basis.

\(^5\) Of course, if $c(e_o, e_u) + f(e_o, e_u) > \theta_h$ then the firm will shut down.

\(^6\) Differentiating $[\theta_l - c(l) - f(l)]/[\theta_h - c(l) - f(l)]$ with respect to $c(l)$, we get $d\ln [\theta_l - c(l) - f(l)]/[\theta_h - c(l) - f(l)] = (\theta_h - \theta_l)/[\theta_h - c(l) - f(l)] < 0$. Similarly, it can be shown that $d\ln [\theta_l - c(l) - f(l)]/[\theta_h - c(l) - f(l)] < 0$.

\(^7\) Assumption (A.3) by itself does not imply that socially optimal care is one in both dimensions. In the absence of (A.4) it is possible that a decrease in care from $e_o, e_u = (1, 1)$ increases welfare by decreasing the firm’s marginal cost and thereby its price (and increasing the output). However with (A.4), any increase in output that is obtained by decreasing induced care is not desirable because it is not socially desirable to sell to the low valuation types unless care is exercised in both dimensions.

\(^8\) See 40 CFR 112.8(b).

\(^9\) See 40 CFR 112.7(a)(5)(c).
To facilitate comparison with later results, we present this result as a proposition.

**Proposition 1.** With regulation alone, \( e_o^* = 1, e_u^* = 0 \), i.e. the firm exercises care only in the observable dimension.

As can be easily seen, this result holds regardless of which dimension - observable or unobservable - is more costly and irrespective of whether the efforts are complements or substitutes.

### 3.1.2. Strict liability only

Following Shavell (1984), we assume that the strict liability rule is imperfect in the sense that even when the firm is responsible for an accident, it is found liable only with probability \( q < 1 \). Also, as in Shavell (1984) we assume that the firm, if found liable, has to pay only the damages \( D \), i.e. there are no penalty multipliers.

We discuss the use of penalty multipliers in the next section. With strict liability alone, the firm will choose \( (e_o^*, e_u^*) \) to minimize its full cost

\[
c(0, e_o) + qH(0, e_o)
\]

With \( e_o = e_o^* = 1 \), the firm's full cost is \( \psi_o + \psi_u + qH_1 \); with \( e_u = 1, e_o = 0 \), the full cost is \( \psi_o + qH_1 \); with \( e_o = e_u = 1 \), this cost is \( \psi_o + qH_1 \); finally, with \( e_o = e_u = 0 \), this cost is \( qH_0 \). Comparing these costs we get:

**Proposition 2.** (1a) When observable effort is more costly (i.e. \( \psi_o > \psi_u \)) and \( \psi_o/\psi_u < (H_1 - H_2)/(H_0 - H_1) \) then for \( q < (\psi_o + \psi_u)/(H_0 - H_2) \) the firm chooses \( e_o^* = 0, e_u^* = 0 \), and for \( q \geq (\psi_o + \psi_u)/(H_0 - H_2) \) the firm chooses \( e_u^* = 1, e_o^* = 1 \). (1b) When observable effort is more costly and \( (\psi_o/\psi_u) \geq (H_1 - H_2)/(H_0 - H_1) \), then for \( q < (\psi_o/\psi_u)/(H_0 - H_1) \) the firm chooses \( e_o^* = 0, e_u^* = 0 \); for \( q \in [(\psi_o/(H_0 - H_1), \psi_o/(H_1 - H_2)) \) it chooses \( e_o^* = 0, e_u^* = 1 \); and for \( q \geq \psi_o/(H_1 - H_2) \) it chooses \( e_o^* = 0, e_u^* = 1 \).

(2a) When the unobservable effort is more costly (i.e. \( \psi_u > \psi_o \)) and \( (\psi_u/\psi_o) < (H_1 - H_2)/(H_0 - H_1) \) then for \( q < (\psi_u + \psi_o)/(H_0 - H_2) \) the firm chooses \( e_o^* = 0, e_u^* = 0 \), and for \( q \geq (\psi_u + \psi_o)/(H_0 - H_2) \) it chooses \( e_o^* = 1, e_u^* = 1 \). (2b) When the unobservable effort is more costly and \( (\psi_u/\psi_o) \geq (H_1 - H_2)/(H_0 - H_1) \), then for \( q < (\psi_u/\psi_o)/(H_0 - H_1) \) the firm chooses \( e_o^* = 0, e_u^* = 0 \); for \( q \in [(\psi_u/(H_0 - H_1), \psi_u/(H_1 - H_2)) \) it chooses \( e_o^* = 1, e_u^* = 0 \); and for \( q \geq \psi_u/(H_1 - H_2) \) it chooses \( e_o^* = 1, e_u^* = 1 \).

The proposition says that if the difference in costs between the more costly effort and the cheaper effort is not very large (i.e. \( (H_0 - H_1)/(H_1 - H_2) < (\psi_o/\psi_u)/(H_1 - H_2)/(H_0 - H_1) \) then depending on the size of \( q \), the firm either exercises no care (which is inefficient), or exercises care in both the dimensions (which is socially optimal). But if the difference in costs is sufficiently large, then for very low values of \( q \) the firm exercises no care; for an intermediate range of \( q \) it exercises care in only the cheaper dimension; and for high enough \( q \) values, it exercises care in both dimensions.

The reason for the difference in these two cases is the following: complementarity of efforts implies that marginal gain from care in the second dimension is greater than marginal gain from care in the first dimension. This implies that for any \( q \) for which the firm prefers to exercise care in the cheaper dimension alone (rather than exercising no care), it will also find it worthwhile to exercise care in the more costly dimension, provided the difference in cost between the two dimensions is not very large. Hence, we have either \( (e_o^* = 0, e_u^* = 0) \) or \( (e_o^* = 1, e_u^* = 1) \) when the cost difference is small. But if this cost difference is large, then for some \( q \) values the firm prefers to exercise care in the cheaper dimension alone.

### 3.1.3. Joint use of regulation and strict liability

Now suppose that the firm has to satisfy a regulatory standard of \( S_j = 1 \) in dimension \( e_o \) and also faces strict liability. Then the firm will choose \( e_o \) to minimize

\[
c(1, e_o) + qH(1, e_o)
\]

Solving this problem we get:

**Proposition 3.** With joint use of regulation and strict liability, the firm chooses, \( e_o^j = 1, e_u^j = 0 \) for \( q < \psi_u/(H_1 - H_2) \); and for \( q \geq \psi_u/(H_1 - H_2) \) the firm chooses \( e_o^j = 1, e_u^j = 1 \).

This result is independent of which effort, observable or unobservable, is more costly. Regulation forces the firm to exercise care in the observable dimension, regardless of whether it is cheaper or more costly, and regardless of the value of \( q \). Given that, the firm compares the marginal gain from care in the unobservable dimension, \( q(H_1 - H_2) \), with the cost of care \( \psi_o \) in that dimension to decide whether to also exercise unobservable care.

We can now compare the various rules using Propositions 1–3. To make this easier, the firm's effort choices are reproduced in Figs. 1–4. Figs. 1 and 2 (respectively, 3 and 4) show effort choices when \( \psi_o > \psi_u \) (respectively, \( \psi_u < \psi_u \)). As can be seen in Fig. 1, for \( q \in \psi_o/(H_1 - H_2), (\psi_o + \psi_u)/(H_0 - H_2) \) joint use is strictly superior to both regulation and strict liability rules used.

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Fig. 2. $\psi_o > \psi_u$ and $(\psi_o/\psi_u) > (H_1 - H_2)/(H_0 - H_1)$.

alone.\(^\dagger\) Under regulation alone, the firm chooses $e_o = 1$ and $e_u = 0$; under strict liability alone, it chooses $e_o = 0, e_u = 0$; whereas under joint use it chooses the socially optimal care $e_o = e_u = 1$.

Similarly, it can be seen in Figs. 2 and 3 that joint use is strictly superior when $q \in (\psi_u/(H_1 - H_2), \psi_u/(H_1 - H_2))$ and $q \in (\psi_u/(H_1 - H_2), (\psi_u + \psi_u)/(H_0 - H_2))$, respectively. In Fig. 4, however, we find that for any given $q$, either strict liability or regulation alone can perform as well as joint use. Hence, if the unobservable effort is sufficiently more costly than the observable effort then joint use does not increase welfare. However, for any other case, there exists a range of $q$ in which joint use is strictly superior.

The intuition behind these results is the following: to decide whether to exercise care in any dimension, the firm compares the reduction in its expected penalty payment with the cost of care. The former is positively related to $q$, the likelihood that the firm is convicted for an accident. When this likelihood is sufficiently large, the reduction in expected penalty is large enough so that strict liability alone induces the firm to exercise care in both dimensions. Therefore, strict liability is as good as joint use. On the other hand for sufficiently small $q$ (for example, $q < \psi_u/(H_1 - H_2)$), the

\(^\dagger\) Note that conditions $\psi_o > \psi_u$ and $(\psi_o/\psi_u) < (H_1 - H_2)/(H_0 - H_1)$ in Fig. 1 imply that $(\psi_o + \psi_u)/(H_0 - H_2)$ lies between $\psi_u/(H_1 - H_2)$ and $\psi_u/(H_0 - H_1)$.
reduction is so small that the firm is not induced to exercise care in the unobservable dimension, even when forced to exercise care in the observable dimension. Hence, regulation performs as well as joint use. This explains why for sufficiently large or sufficiently small q, either regulation alone or strict liability alone perform as well as joint use. Let us see why joint use may perform better than both of these in an intermediate range of q values. Take a small enough q (for example, q < \psi_u/(H_1 - H_2)) for which strict liability alone either does not induce care in any dimension, or induces care in only the cheaper dimension. In the former case, to attain (e_1^o = 1, e_1^s = 1) q has to increase by a sufficient amount to induce care in both dimensions. In the latter case, q has to increase enough to induce care in the more costly dimension. Whereas under joint use, to attain (e_1^o = 1, e_1^s = 1), q has to increase only enough to induce care in the unobservable dimension. When the unobservable care is the cheaper care (Figs. 1 and 2), clearly the increase in q required under joint use is smaller, and hence it does strictly better in some range. Similar reasoning applies when the unobservable care is the more costly care, if for any q < \psi_u/(H_1 - H_2) strict liability does not induce care in either dimension. However, when the unobservable care is the more costly care and strict liability induces care in the cheaper dimension (i.e. e_2^o = 1) for some q < \psi_u/(H_1 - H_2), the increase in q required under both joint use and strict liability alone to attain e_0 = 1, e_1 = 1 is the same (see Fig. 4). In both cases, q has to increase just enough to induce care in the unobservable dimension. Hence, in this case, there is no range of q where joint use performs strictly better than both strict liability and regulation.

3.2. When efforts are substitutes

The relevant cases when efforts are substitutes (as defined in Eq. (2)) are: \((\psi_o/\psi_u) > (H_1 - H_2)/(H_0 - H_1)\) when observable effort is more costly, and \((\psi_u/\psi_o) > (H_1 - H_2)/(H_0 - H_1)\) when unobservable effort is more costly.\(^{12}\) The firm’s effort choice in these cases can be described in exactly the same manner as set forth in Propositions 1–3.\(^{13}\) For any given rule, the expressions for the critical q values (those values at which the firm’s care choice changes under that rule) and their ordering remain the same whether efforts are complements or substitutes. However, the magnitude of q values which are critical under strict liability, relative to the magnitude of q values which are critical under joint use, can be different when efforts are substitutes than when they are complements. In particular, in the case of substitutes, we have \(\psi_u/(H_0 - H_1) < \psi_u/(H_1 - H_2)\), whereas in case of complementary efforts we had \(\psi_u/(H_0 - H_1) > \psi_u/(H_1 - H_2)\). This affects the relative superiority of different rules when \(\psi_o > \psi_u\). With complementary efforts, we found joint use to be at least as good as strict liability alone, for any q. This is not necessarily the case when the efforts are substitutes. While there is a range of q values for which joint use is strictly superior to both regulation and strict liability alone, there is also a range of q values for which joint use may be worse than strict liability.

See Fig. 5, which reproduces the results from these propositions for the \(\psi_o > \psi_u\) case and with the ordering of critical q values relevant for the substitutes case. For q \(\in (\psi_u/(H_0 - H_1), \psi_u/(H_1 - H_2))\), under strict liability alone we have \(e_0^s = 0\) and \(e_1^s = 1\); and under joint use we have \(e_0^j = 1\) and \(e_1^j = 0\). In this range q is not large enough to induce effort in both dimensions and therefore adding regulation to strict liability causes the firm to substitute the observable (and more costly) effort for the cheaper effort in the unobservable dimension. Consequently, joint use results in a higher social and private marginal cost of production than strict liability alone. The effect of this on welfare is not obvious and depends on parameter values. On the one hand joint use is worse because it results in a higher social marginal cost. But on the other hand it also makes it more likely that the firm will price the low-valuation consumer out of the market (because private marginal cost is also higher), which is desirable given that care is exercised in only one dimension (see Assumption (A.4)).

Any q \(\in (\psi_u/(H_1 - H_2), \psi_o/(H_1 - H_2))\) is large enough for liability to induce effort in the cheaper dimension, given that the firm is exercising care in the more costly dimension. However, if the firm is not taking care in the costly dimension, then this q is still not large enough for strict liability alone to induce effort in both the dimensions. Hence, in this range joint use performs better than both strict liability alone and regulation alone.

Fig. 6 shows that when the unobservable effort is more costly, then for any q, either regulation alone or strict liability alone does as well as joint use. This is what we found for complementary efforts when the cost difference between the two efforts is sufficiently large (i.e. when \((\psi_u/\psi_o) > (H_1 - H_2)/(H_0 - H_1)\)).

\(^{12}\) Note that Assumption (A.3) rules out perfect substitutability (i.e. \(H_1 - H_2 = 0\)) between the efforts in different dimensions. (A.3) implies that given effort in one of the dimensions, the effort in the second dimension reduces the expected damage by a greater amount than the cost of this effort. If efforts were perfect substitutes, this could not happen with any positive cost of effort.

\(^{13}\) The proofs of the mentioned propositions (see the Appendix) do not utilize the property of the complementarity of the efforts, and hence apply regardless of whether efforts are complements or substitutes.
4. Penalty multipliers and joint use

In the previous section we found that in the absence of penalty multipliers joint use may be superior to both regulation and strict liability alone because it induces socially optimal care for a greater range of q. Once we allow for penalty multipliers in that setup, strict liability alone is able to induce socially optimal care. For example, consider the case when \( \psi_o > \psi_u, (\psi_o/\psi_u) < (H_1 - H_2)/(H_0 - H_1) \), and \( q \in (\psi_o/(H_1 - H_2), (\psi_o + \psi_u)/(H_0 - H_2)) \). In the absence of a penalty multiplier, strict liability alone does not induce care in any dimension (see Fig. 1). But with any penalty multiplier, \( m \geq ((\psi_o + \psi_u)/(H_0 - H_2))/q \), the firm can be induced to exercise \( e_o = 1 \) and \( e_u = 1 \). This does not, however, mean that penalty multipliers and joint use are perfect substitutes. While both can induce socially optimal care, joint use may be able to do so with lower expected liability costs for the firm. In case we believe that higher liability costs can diminish welfare (as in our model) then joint use may be superior to strict liability alone even in the presence of penalty multipliers. To show this formally, we compare the rule of strict liability alone with joint use when \( \psi_o > \psi_u, (\psi_o/\psi_u) < (H_1 - H_2)/(H_0 - H_1) \), and \( q \in (\psi_o/(H_1 - H_2), (\psi_o + \psi_u)/(H_0 - H_2)) \).

4.1. Strict liability alone

With strict liability alone, any multiplier \( m_s \) smaller than \( ((\psi_o + \psi_u)/(H_0 - H_2))/q \) fails to induce care in both dimensions; whereas any \( m_s \geq ((\psi_o + \psi_u)/(H_0 - H_2))/q \) induces care in both dimensions. Since welfare is unambiguously higher when care is exercised in both dimensions, it is clear that any \( m_s \) exceeding \( ((\psi_o + \psi_u)/(H_0 - H_2))/q \) results in a higher welfare than any \( m_s < ((\psi_o + \psi_u)/(H_0 - H_2))/q \). Therefore, the optimal penalty multiplier cannot be smaller than \((\psi_o + \psi_u)/(H_0 - H_2)/q\). For any multiplier greater than \((\psi_o + \psi_u)/(H_0 - H_2)/q\) the firm exercises care in both dimensions. With care in both dimensions, it is socially desirable that both high- and low-valuation consumers consume the product. Now the firm is more likely to charge a lower price of \( \theta_l \) and sell to both types of consumers the lower is its expected liability cost (which is, \( m_s q H_2 \)). Since this cost increases as \( m_s \) increases, the optimal penalty multiplier under strict liability is \( m_s = ((\psi_o + \psi_u)/(H_0 - H_2))/q \). With \( m_s = ((\psi_o + \psi_u)/(H_0 - H_2))/q \), the firm charges \( \theta_l \) for the product and serves all consumers if and only if

\[
\alpha < \theta_l - \psi_o - \psi_u - ((\psi_o + \psi_u)/(H_0 - H_2)H_2)
\]

If condition (5) is not satisfied then the firm charges \( \theta_h \) and serves only the high-valuation consumers. Hence, we have:

**Remark 1.** When \( \psi_o > \psi_u, (\psi_o/\psi_u) < ((H_1 - H_2)/(H_0 - H_1)) \) and \( q \in (\psi_o/(H_1 - H_2), (\psi_o + \psi_u)/(H_0 - H_2)) \), the optimal penalty multiplier under strict liability alone is \( m_s = ((\psi_o + \psi_u)/(H_0 - H_2))/q \). With this multiplier, welfare is

\[
W = \{H_0[\alpha \theta_h + (1 - \alpha)\theta_l - \psi_o - \psi_u - H_2]\}.
\]

For any multiplier exceeding \( ((\psi_o + \psi_u)/(H_0 - H_2))/q \) the firm exercises care in both dimensions and hence the welfare is

\[
W = \{H_0[\alpha \theta_h - \psi_o - \psi_u - H_2]\}.
\]

4.2. Joint use of regulation and strict liability

For the assumed scenario \( (\psi_o > \psi_u, (\psi_o/\psi_u) < ((H_1 - H_2)/(H_0 - H_1)) \) and \( q \in (\psi_o/(H_1 - H_2), (\psi_o + \psi_u)/(H_0 - H_2)) \), the firm's full marginal cost is \( \psi_o + \psi_u + q H_2 \), which implies that the firm will charge \( \theta_l \) and serve all consumers if

\[
\alpha < \theta_l - \psi_o - \psi_u - q H_2,
\]

otherwise, it will charge \( \theta_h \) and serve only the high-valuation consumers. This gives:

**Remark 2.** When \( \psi_o > \psi_u, (\psi_o/\psi_u) < ((H_1 - H_2)/(H_0 - H_1)) \) and \( q \in (\psi_o/(H_1 - H_2), (\psi_o + \psi_u)/(H_0 - H_2)) \) and the penalty multiplier is restricted to be greater than or equal to one, then under joint use we have

\[
W = \{H_0[\alpha \theta_h + (1 - \alpha)\theta_l - \psi_o - \psi_u - H_2]\}.
\]

For any penalty multiplier the optimal penalty multiplier under joint use is \( m_s = ((\psi_o + \psi_u)/(H_0 - H_2))/q \). With \( m_s = ((\psi_o + \psi_u)/(H_0 - H_2))/q \), the firm charges \( \theta_l \) for the product and serves all consumers if and only if

\[
\alpha < \theta_l - \psi_o - \psi_u - ((\psi_o + \psi_u)/(H_0 - H_2)H_2).
\]

For any multiplier exceeding \( ((\psi_o + \psi_u)/(H_0 - H_2))/q \) the firm exercises care in both dimensions and hence the welfare is

\[
W = \{H_0[\alpha \theta_h - \psi_o - \psi_u - H_2]\}.
\]
Since \( q < (\psi_0 + \psi_d)/(H_0 - H_2) \), the RHS of Eq. (6) is greater than the RHS of Eq. (5). This implies that the firm charges the lower price for a greater range of \( \alpha \) values under joint use than it does under strict liability alone. This means welfare is more likely to be larger under joint use than under strict liability alone.

In fact, if the multiplier is not restricted to be larger than one, then by choosing \( m_j = (\psi_a/(H_1 - H_2))/q \), the welfare under joint use can be further increased. With the multiplier \( m_j = (\psi_a/(H_1 - H_2))/q \) under joint use, the firm still exercises care in both dimensions but has a lower full marginal cost, \( \psi_a + \psi_d + (\psi_a/(H_1 - H_2))H_2 \). As above, this implies:

\[ \text{Remark 3. When } \psi_0 > \psi_a, (\psi_a/\psi_d) < (H_1 - H_2)/(H_0 - H_1), \text{ and } q \in (\psi_a/(H_1 - H_2), (\psi_a + \psi_d)/(H_0 - H_2)) \text{ and the penalty multiplier is not restricted to be greater than one, the optimal penalty multiplier under joint use is } m_j = (\psi_a/(H_1 - H_2))/q \text{. With this multiplier, we have } W = N[\alpha\theta_1 + (1 - \alpha)\theta_2 - \psi_0 - \psi_a - (\psi_a/(H_1 - H_2)H_2)/\theta_2 \psi_0 - \psi_a - (\psi_a/(H_1 - H_2)H_2)], \text{ and } W = \alpha N[\theta_1 - \psi_0 - \psi_a - (\psi_a/(H_1 - H_2))H_2] \text{ otherwise.} \]

That is, if the penalty multiplier is allowed to be smaller than one, higher welfare is realized under joint use for an even greater range of \( \alpha \) values. By reducing the penalty, the firm’s marginal cost of production can be reduced without affecting its care decision. While the above discussion was for the particular case \( \psi_0 > \psi_a, (\psi_a/\psi_d) < (H_1 - H_2)/(H_0 - H_1) \), and \( q \in (\psi_a/(H_1 - H_2), (\psi_a + \psi_d)/(H_0 - H_2)) \), similar reasoning shows that joint use remains superior for any set of parameter values for which it was superior in the absence of penalty multipliers.

In fact, presence of penalty multipliers further strengthens the case for joint use. Joint use now results in a higher welfare than regulation alone or strict liability alone for a greater set of parameter values than found in the previous section. This is true even if penalty multipliers are restricted to be greater than or equal to one. For example, when \( \psi_0 > \psi_a, (\psi_a/\psi_d) < (H_1 - H_2)/(H_0 - H_1) \), and \( q < (\psi_a/(H_1 - H_2)) \), we found joint use and regulation to be equivalent in the absence of multipliers (see Fig. 1). Now by choosing \( m_j = (\psi_a/(H_1 - H_2))/q \), welfare under joint use can be made higher than welfare under regulation alone or strict liability alone.

If the penalty multiplier is allowed to be smaller than one, then the case for joint use is strengthened even further. For example, when \( \psi_0 > \psi_a, (\psi_a/\psi_d) < (H_1 - H_2)/(H_0 - H_1) \), and \( q < (\psi_a/(H_1 - H_2)) \), we found joint use and strict liability to be equivalent in the previous section (see Fig. 1). They both induce the firm to exercise care in both dimensions and in the absence of penalty multipliers, they result in the same expected liability cost. However, by choosing the appropriate penalty multipliers \( m_j = (\psi_a/(H_1 - H_2))/q \) under joint use and \( m_f = (\psi_a + \psi_d)/(H_0 - H_2) \) under strict liability the expected liability cost can be decreased by a greater amount under joint use. This is because with joint use the expected liability cost has to be just high enough to induce care only in the unobservable dimension, whereas with strict liability alone, the expected liability cost has to be high enough to induce care in both dimensions.\(^{18}\) This implies a greater likelihood of a lower price, higher output and therefore higher welfare under joint use than under strict liability alone.

By extension, this also means that if expected liability costs matter and penalty multipliers are allowed and not restricted to be greater than one, then joint use may be beneficial even when there is no uncertainty of conviction.\(^{19}\) That is, in addition to relaxing the assumptions of judgment-proofness, heterogeneous harm levels and heterogeneous wealth levels made in Shavell (1984) and Schmitz (2000), we can also relax the assumption of conviction uncertainty and still justify joint use of strict liability and regulation if other conditions, such as multidimensional care and a negative relationship between the firm’s expected liability cost and social welfare, are present.

We must emphasize that the assumption that the firm has market power is crucial for our results regarding superiority of joint use in the presence of penalty multipliers. In a perfectly competitive environment where price equals marginal cost, joint use may not increase welfare by decreasing expected liability costs; in fact, employing the smaller multiplier under joint use that is just sufficient to induce socially optimal care can actually reduce welfare. For example, consider a perfectly competitive market with the standard downward sloping demand curve (such as in Polinsky, 1980), where firms set price equal to full private marginal cost of production. In this case, social optimality requires that a firm’s full private marginal cost be the same as social marginal cost of production, which is \( \psi_0 + \psi_d + H_2 \) in terms of our notation. This in turn requires that the penalty multiplier be equal to \( 1/q \), which is larger than the minimum multiplier \( m_\alpha = ((\psi_0 + \psi_d)/(H_0 - H_2))/q \) required to induce optimal care under strict liability alone (in the example case we consider above, with \( \psi_0 > \psi_a, (\psi_a/\psi_d) < (H_1 - H_2)/(H_0 - H_1) \), and \( q \in (\psi_a/(H_1 - H_2), (\psi_a + \psi_d)/(H_0 - H_2)) \)). That is, use of \( m_\alpha = ((\psi_0 + \psi_d)/(H_0 - H_2))/q \) with strict liability alone would result in a lower price and a higher output than is socially optimal. Employing joint use with its even smaller multiplier, \( m_j = (\psi_a/(H_1 - H_2))/q \), would further exacerbate this inefficiency.\(^{20}\)

5. Concluding remarks

In Section 1 to our paper, we noted that many activities that carry a risk of an accident are characterized by joint use of regulation and a liability mechanism; both observable and unobservable care, and conviction uncertainty. Historically, economists have invoked judgment-proofness as the theoretical justification for joint use. However, as Innes (2004) and others have noted, this justification is not entirely satisfactory. The “take-home” result of our paper is that if the harming party can take both observable and unobservable care, then joint use can be socially advantageous without the judgment-proofness assumption. This is true even when penalty multipliers are allowed, provided social welfare is negatively related to the firm’s expected liability costs. The extent to which this result obtains depends upon (a) the relative costs of the observable and unobservable care, (b) whether the care types are substitutes or complements, and (c) the degree of uncertainty over conviction.\(^{21}\)

The concept of unobservable care has much in common with emerging literatures regarding endogenous monitoring (see Millock & Zilberman, 2002), environmental self-auditing (see Pfaff & Sanchirico, 2000; Friesen, 2006), and morality versus law as regulators of conduct (see Shavell, 2002). In each of these three cases, scholars are exploring optimal strategies for mitigating harm, given the fact that potentially harming parties can take unobservable care that is cheap compared to their own observable

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\(^{18}\) Under joint use \( m_j = (\psi_a/(H_1 - H_2))/q \) induces care in both dimensions, whereas under strict liability alone, the multiplier has to be \( m_f = ((\psi_0 + \psi_d)/(H_0 - H_2))/q > m_j \).

\(^{19}\) Lack of conviction uncertainty implies \( q = 1 \), which is just a special case of \( q > (\psi_0 + \psi_d)/(H_0 - H_2) \) that we considered in the paragraph above.

\(^{20}\) We are grateful to an anonymous referee for providing this example.

\(^{21}\) When penalty multipliers are not restricted to be greater than one, and a negative relationship between the firm’s liability costs and social welfare exists, the efficiency of joint use does not depend on uncertainty of conviction.
care and to unobservable or observable care taken by harmed parties or the regulator. Our work is related to these literatures in that we are also concerned with efficient motivation of unobservable care and suggest how joint use of regulation and liability may do this more effectively than liability alone.

It is interesting to consider how our results regarding joint use may change if we impose a negligence rule instead of strict liability. If we strictly restrict ourselves to the setting in this paper (an observable dimension of care that can be regulated and an unobservable dimension that cannot be regulated) then a negligence rule has no role to play since negligence cannot really be used when care is unobservable. However, a justification similar to that provided here for joint use of regulation and strict liability can also be given for joint use of regulation and negligence when there is multidimensional care, the care in different dimensions is observable, but care in some dimensions is not regulated (say, due to lengthy administrative procedures and formalities involved in passing new regulations, it may be slow to respond to what is believed to be the best practice in an industry). In this case, a negligence rule along with regulation will provide better incentives than either of those alone, just as joint use of strict liability and regulation does in this paper.

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Appendix

Proof of Proposition 1. Is obvious from the discussion preceding the proposition. □

Proof of Proposition 2. Part (1a): Note that when observable effort is more costly then \( q_o + qH > q_o + qH_1 \), which clearly implies \((e_0^2 = 0, e_1^2 = 1) \) or \((e_0^2 = 1, e_1^2 = 0) \) for all \( q \). That is, the firm will never exercise observable care alone; it prefers to exercise unobservable care alone to exercising observable care alone.

Step 1: Taking the above as given, we now first prove that for \( q < \langle (q_o + qH)/(H_0 - H_2) \rangle \) the firm chooses \((e_0^2 = 0, e_1^2 = 0) \). To prove this we need to show that (i) \( qH_0 < qH_1 + qH_2 \) and (ii) \( qH_0 < qH_1 + qH_2 \). Since \( q < \langle (q_o + qH)/(H_0 - H_2) \rangle \), the former is clearly true. The latter is true if and only if \( q < \langle (q_o + qH)/(H_0 - H_2) \rangle \). Subtracting \( (q_o + qH)(H_0 - H_2) \) from \( (q_o + qH)(H_0 - H_1) \) we get, \( \langle (q_o + qH)/(H_0 - H_2) \rangle - \langle (q_o + qH)/(H_0 - H_1) \rangle > 0 \) since \( \langle (q_o + qH)/(H_0 - H_2) \rangle \geq 0 \) since \( \langle (q_o + qH)/(H_0 - H_1) \rangle \). Therefore, \( q < \langle (q_o + qH)/(H_0 - H_2) \rangle \) implies \( q < \langle (q_o + qH)/(H_0 - H_1) \rangle \).

Step 2: Now we show that for \( q \in \left[ \langle (q_o + qH)/(H_0 - H_1) \rangle, \langle (q_o + qH)/(H_0 - H_2) \rangle \right] \) the firm chooses \((e_0^2 = 0, e_1^2 = 1) \). To prove this, we need (i) \( qH_0 + qH_1 \leq qH_0 + qH_2 \) and (ii) \( qH_0 + qH_1 \leq qH_0 + qH_2 \). Since \( q \geq \langle (q_o + qH)/(H_0 - H_1) \rangle \), the former is clearly true. Similarly, \( q \geq \langle (q_o + qH)/(H_0 - H_2) \rangle \) implies \( qH_1 < qH_2 \), which implies \( qH_1 < qH_0 + qH_2 \).

Step 3: To show that for \( q \geq \langle (q_o + qH)/(H_0 - H_2) \rangle \) the firm chooses \((e_0^2 = 1, e_1^2 = 1) \), we need to show that (i) \( qH_0 + qH_2 < qH_0 + qH_1 \) and (ii) \( qH_0 + qH_2 < qH_0 + qH_1 \). The latter follows easily from the fact that \( q \geq \langle (q_o + qH)/(H_0 - H_2) \rangle \). The former requires \( q \geq \langle (q_o + qH)/(H_0 - H_2) \rangle \). Subtracting \( (q_o + qH)/(H_0 - H_2) \) from \( (q_o + qH)/(H_0 - H_1) \) we get, \( \langle (q_o + qH)/(H_0 - H_2) \rangle - \langle (q_o + qH)/(H_0 - H_1) \rangle > 0 \) since \( \langle (q_o + qH)/(H_0 - H_1) \rangle \). Hence, \( q \geq \langle (q_o + qH)/(H_0 - H_2) \rangle \), which is what we needed.

The proof of part (2a) (respectively, (2b)) is identical to (1a) (respectively, (1b)) with \( \psi_o \) replaced by \( \psi_u \) and \( \psi_o \) replaced by \( \psi_o \) in the above proof. □

Proof of Proposition 3. Suppose \( q < \langle (q_o + qH)/(H_1 - H_2) \rangle \). Then, \( qH_1 + qH_2 < qH_2 + qH_1 + qH_2 \). i.e. it is better for the firm to exercise \((e_0^2 = 1, e_1^2 = 0) \). With regulation in dimension \( e_o \), the firm has to exercise care in that dimension, i.e. \((e_0^2 = 0, e_1^2 = 1) \) and \((e_0^2 = 0, e_1^2 = 0) \) are not feasible. This gives \( e_0^2 = 1 \) and \( e_1^2 = 0 \).

Now suppose \( q \geq \langle (q_o + qH)/(H_1 - H_2) \rangle \). In this case, \( qH_1 + qH_2 > qH_2 + qH_1 + qH_2 \). i.e. the firm prefers \((e_0^2 = 1, e_1^2 = 1) \) to \((e_0^2 = 1, e_1^2 = 0) \). Hence, we get \( e_0^2 = 1 \) and \( e_1^2 = 1 \), the socially optimal outcome. □

References


