Prevention and Cleanup of Dynamic Harm Under Environmental Liability

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Abstract

This paper explores incentives for preventing an accident and cleanup after an accident when firms are subject to environmental liability. In our two-period setup, the level of environmental harm in the second period depends on first-period harm when cleanup was incomplete. Under strict liability, in the first period, firms with a positive probability of going out of business after the first period have inadequate prevention and cleanup incentives. The fundamental disconnect between private incentives and social optimality cannot be remedied with a damages multiplier. Under negligence with a cause-in-fact requirement, incentive problems remain whereas, under negligence without cause-in-fact, first-best incentives may emerge and a simple punitive damages multiplier can ensure the efficient solution.

Keywords: environmental liability law, prevention, cleanup, care, environmental harm

JEL-Classification: K 13, Q 58

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1 Introduction

1.1 Motivation and main results

The environment is a complex system. The environmental harm imposed by an accident often depends on the occurrence of previous adverse events. In many environmental contexts, when cleanup is incomplete, the environment will be more susceptible afterwards. For example, using natural resources beyond a defined tipping point may have disastrous consequences for the environment (e.g., Lenton et al. 2008). One implication of an accident today may thus be the need for more precautions in the future, such that the marginal benefits from higher precautions today include the avoidance of higher costs in the future. When long time horizons are relevant, inducing polluters to internalize their influence on these future social costs may be challenging. This is underscored, for example, by the fact that about 35% of remediation expenditures in the European Union come from public budgets because legally responsible polluters no longer exist, cannot be identified, or are insolvent (EPA 2009). When it comes to dynamic harm, the scenario in which incomplete cleanup increases future harm is complemented by the case in which future harm decreases. For example, when some piece of land was contaminated by an accident and is not (or cannot) be completely cleaned up, the adverse repercussions of a further accident may be lower due to the first accident (e.g., as the land is not used for residential purposes).

This paper considers incentives to prevent environmental harm ex ante or mitigate it ex post in a simple two-period setting in which injurers are subject to environmental liability and the potential second-period harm depends on the level of environmental harm remaining after the first period. We analyze environmental liability law in terms of two alternative liability rules: strict liability and negligence. Under strict liability, the polluter is required to compensate the victim independent of his prevention or treatment behavior. Under negligence, the polluter’s being held liable is contingent on the breach of a behavioral norm. Which liability rule applies commonly depends on the activity undertaken. For instance, the Environmental Liability Directive of the European Union lists activities which are subject to strict liability, while other activities are subject to negligence.
We find that neither strict liability nor negligence ensure socially optimal prevention and cleanup levels in the first period when firms anticipate that they may be out of business in the second period. In contrast, behavior in the second period is efficient given first-period choices. Under strict liability, firms discount the additional influence on payoffs in the second period and thus choose inefficient prevention and cleanup levels. Even though the distortion is due to a positive probability of being no longer in charge in period 2, the standard remedy – a damages multiplier – cannot be relied upon because two different behaviors are affected. In contrast, under negligence without a cause-in-fact requirement, efficient choices will certainly result when a damages multiplier is used. With a cause-in-fact requirement, negligence induces inefficient first-period choices with and without a damages multiplier. As a result, the clear ranking of liability rules only emerges for negligence that implies a discontinuity in the injurer’s cost function.

1.2 Related literature

Our paper contributes to the literature about environmental liability, which is relatively scarce. The papers most closely related to our analysis are Barrett and Segerson (1997), Endres and Friehe (2015) and Polinsky and Shavell (1994). The latter provide the first study of a scenario in which firms determine both prevention and treatment in a static setting. In contrast, the present paper uses a two-period framework to highlight the mechanism of interest. Barrett and Segerson (1997) build on Polinsky and Shavell (1994) by considering policy objectives other than Pareto optimality. Endres and Friehe (2015) consider the question of how to arrive at an adequate measure of compensation when cleanup is possible in a setting with victim care.

Our mechanism uses the assumption that firms account for the possibility that they will go out of business in the long term. This may be likened to the case in which private actors have a discount rate that differs from the socially relevant one. Endres et al. (2007) study this scenario with a focus on private incentives for improving the precaution technology, where certain investments today are met by benefits in the future that will be discounted by the inadequate discount factor. In the literature about potentially judgment-proof injurers
or about the disappearing defendant (e.g., Dari-Mattiacci and Mangan 2008), the injurer also internalizes only a share of the potential adverse consequences (either due to the limited ability to pay or due to the possibility that victims will not sue). The innovation of the present paper primarily lies in the consideration of dynamic harm in a setup where prevention and cleanup is possible. Moreover, the present paper touches upon the issue of multiple tortfeasors because when the first firm goes out of business and the second-period firm experiences an accident, both the first- and the second-period firm have influenced the level of harm in the second period (e.g., Kornhauser and Revesz 2009). In our setup, due the verifiable sequence of moves and the relatively long time periods imagined, it is assumed that courts understand the individual contributions to second-period harm, removing to some extent a key issue of that literature. However, we will comment on it below.

The structure of the paper is as follows: Section 2 presents the model and the social optimum. Decentralized private decision-making when individuals are subject to strict liability is described in Section 3. Section 4 offers a discussion of the incentives under negligence. Section 5 concludes.

2 The model and social optimum

2.1 The model

Building on Barrett and Segerson (1997), we consider a very simple model with risk-neutral agents that allows us to illustrate the mechanism of key interest. The wording to be used in the following comes from the context of environmental harm resulting from the release of hazardous waste. It must be borne in mind that the model can also be applied to other contexts (e.g., medical care). We consider a two-period setting, where a single period may represent a relatively long time interval (e.g., 20 years). To save on notation, we do not consider discounting, because it is immaterial to our conclusions when we assume that the private and the social discount factor is the same\footnote{For example, Endres et al. (2007) consider the possibility that the two discount rates may fall apart.}

In period 1, a firm is engaged in a productive activity that creates environmental harm
with probability $p$. For example, the production process may produce hazardous waste as a byproduct which may spill into the ground. With probability $\gamma$, the firm is still active in period 2. The discontinuation probability $1 - \gamma$ may have different explanations. The firm may anticipate in period 1 that it may (i) prefer to enter different lines of business or switch to another location (e.g., as a result of regulatory competition), (ii) cease to exist (in particular when it is a family business), (iii) become insolvent as a result of consumer, competitor or regulatory claims before the arrival of period 2. The first-period firm is replaced by another firm with similar characteristics regarding the productive activity with probability $1 - \gamma$. In each period, the active firm can invest in prevention $x$ to reduce the probability $p(x)$ of environmental harm (e.g., that the hazardous waste enters the environment). The probability is decreasing at a diminishing rate, that is, $p' < 0 < p''$. For simplicity, the accident technology is time-invariant and the cost of precaution is assumed to be $x$.

When environmental harm occurs, cleanup activities $c$ reduce the level of environmental harm remaining. Let us assume that $h(c_0)$ denotes the level of first-period harm remaining when there was an accident and cleanup to the extent $c_0$ applied, where cleanup decreases harm at a decreasing rate (i.e., that $\partial h / \partial c_0 < 0 < \partial^2 h / \partial c_0^2$). In the second period, we have a harm level given by $H(c_n, 0) = h(c_n)$ when there either was no accident in period 1 or when there was an accident with complete cleanup, and by $H(c_a, h(c_0))$ when there was an accident with incomplete cleanup in period 1. Cleanup decreases harm in the second-period also at a diminishing rate. For simplicity, the cost of cleanup is assumed to be $c$. To sharpen our analysis, we assume that full cleanup is never optimal.

For most applications, any harm remaining from earlier incidents will increase the future harm potential. This results from the possibility of accumulation and interaction effects aggravating the adverse consequences of any given release of waste. This scenario with increasing harm (IH) will be analyzed using the assumptions about the partial derivative $\partial H / \partial h > 0$ and the cross partial derivative $\partial^2 H / \partial h \partial c < 0$. The latter assumption implies

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2As we will explain below, our effect is due to the possibility that the first-period firm is no longer undertaking the operation and not so much that it cannot afford to pay.

3This assumption allows us to rely on interior solutions throughout. When the assumption is not fulfilled, the dynamic nature of harm may still introduce inefficiencies.
that cleanup has a higher productivity in terms of lowering the level of second-period harm when there is more harm from the first-period remaining.

In some applications, harm remaining from earlier incidents will decrease the future harm potential, leading to a scenario with decreasing harm (DH). For example, it may be that animal and plant populations are lower in some area due to an earlier incident, thereby limiting the level of harm that can result with respect to these resources. For our analysis, we assume $\partial H/\partial h < 0$ and the cross partial derivative $\partial^2 H/\partial h \partial c > 0$. The latter assumption implies that cleanup has a lower productivity in terms of decreasing the level of second-period harm when there is more harm from the first-period remaining (as the latter lowers $H$).

### 2.2 The social optimum

The policy maker seeks to minimize the level of expected social costs, using the different levels of prevention and treatment. The total expected social cost over the two periods is given by

$$ SC = E_0 + p(x_0)E_a + (1 - p(x_0))E_n, $$

where

$$ E_i = x_i + p(x_i)D_i, \ i = 0, a, n $$

and

$$ D_0 = c_0 + h(c_0) $$

$$ D_a = c_a + H(c_a, h(c_0)) $$

$$ D_n = c_n + h(c_n). $$

The equation (1) shows that whether or not the second-period costs will be $E_a$ or $E_n$ depends upon whether there was an accident in the first period or not. In the scenario IH (DH), the level of costs $E_a$ exceeds (falls short of) the level $E_n$. The difference in the level

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4The sketched limit on environmental harm abstracts from the possibility that the regenerating capability of the animal and plant populations may be knocked out by the second accident; this eventuality would make this case better captured by scenario IH.
of costs in the second period is thus another repercussion of first-period choices, a reality that clearly shows in the rearranged first-order conditions for \((x_0, c_0, x_a, c_a, x_n, c_n)\):

\[
1 = -p'(x_0) [D_0 + E_a - E_n] \tag{6}
\]
\[
1 = -\frac{\partial h(c_0)}{\partial c_0} \left( 1 + p(x_a) \frac{\partial H(c_a, h(c_0))}{\partial h} \right) \tag{7}
\]
\[
1 = -p'(x_a) D_a \tag{8}
\]
\[
1 = -\frac{\partial H(c_a, h(c_0))}{\partial c_a} \tag{9}
\]
\[
1 = -p'(x_n) D_n \tag{10}
\]
\[
1 = -\frac{\partial h(c_n)}{\partial c_n} \tag{11}
\]

The marginal cost of prevention and cleanup is equal to one and arranged on the left-hand side of (6)-(11). The marginal benefit of prevention in the first period manifests in the decrease in the first-period accident probability. The importance of this reduction depends on the level of minimized costs from the accident in the first period, \(D_0\), corrected for the implication for second-period costs, \(E_a - E_n\). For the accident contingency in period 1 which arises with probability \(p(x_0)\), the social planer determines the level of cleanup \(c_0\). A variation in the harm remaining in period 1 has repercussions also for the expected costs in the second period because the level of second-period harm is a function of \(h(c_0)\). The optimal prevention and cleanup choices in the second period are more straightforwardly determined as the marginal benefits and the marginal costs all arise in the same period. For the prevention and cleanup levels after a first-period accident with incomplete cleanup, we obtain a relationship to the level of harm remaining from the first period, that is, to the level of first-period cleanup. These relationships can be described by

\[
\frac{dx_a^*}{dc_0} = -\frac{p'(x_a)}{p''(x_a) D_a} \frac{\partial H(c_a, h(c_0))}{\partial h} \frac{\partial h(c_0)}{\partial c_0} \tag{12}
\]

from (8) and

\[
\frac{dc_a^*}{dc_0} = -\frac{1}{\frac{\partial^2 H(c_a, h(c_0))}{\partial c_a \partial h} \frac{\partial h(c_0)}{\partial c_0}} \tag{13}
\]

from (9).
Lemma 1 The levels of second-period prevention and cleanup after an accident in the first period are decreasing with the level of cleanup in the first period \((\frac{dx_a}{dc_0} < 0 \) and \(\frac{dc_a}{dc_0} < 0\)) in scenario IH and increasing with \(c_0\) \((\frac{dx_a}{dc_0} > 0 \) and \(\frac{dc_a}{dc_0} > 0\)) in scenario DH.

The intuition for the lemma is that a higher level of first-period prevention decreases the level of harm remaining which may either increase or decrease the level of second-period harm. For the prevention and cleanup levels when no accident happened in the first period, there is no such dependence.

We summarize our findings for the social optimum in:

Proposition 1 Social optimum: (i) For the scenario IH with increasing harm, we find that the socially optimal levels of prevention fulfill \(x_a^* > x_n^*\) and \(x_0^* > x_n^*\) and the socially optimal levels of treatment fulfill \(c_0^* > c_n^*\) and \(c_a^* > c_n^*\). (ii) For the scenario DH with decreasing harm, we find that the socially optimal levels of prevention fulfill \(x_a^* < x_n^*\) (while the ranking of \(x_0^*\) and \(x_n^*\) is not clear) and the socially optimal levels of treatment fulfill \(c_0^* < c_n^*\) and \(c_a^* < c_n^*\).

Proof. The claims derive from \([6]-[11]\). With \(h(c) = H(c, 0)\), we get that \(D_0 = D_n\) for a given level of cleanup. At optimal levels of cleanup, we will always have that \(D_n^* < D_0^*\) because \(c_n^*\) minimizes \(D_n\) whereas the choice of \(c_0\) achieves an objective different from minimizing \(D_0\). Since \(E_a - E_n > 0\) by the envelope theorem in scenario IH, we can deduce that \(x_0^* > x_n^*\). In scenario DH, that ranking is less clear due to \(E_a < E_n\) on the one hand and \(D_n^* < D_0^*\) on the other. Since \(D_a - D_n > (\leq) 0\) by the envelope theorem in scenario IH (DH), we can deduce that \(x_a^* > x_n^*\) (\(x_a^* < x_n^*\)). With \(h(c) = H(c, 0)\), we arrive at \(c_0 > c_n\) \((c_0 < c_n)\) in scenario IH (DH) due to the sign of \(\partial H/\partial h\). The ranking of \(c_n\) and \(c_a\) is determined by the assumption about \(\partial^2 H/\partial h\partial c\). ■

For the case in which a previous contamination raises the risk presented by a further contamination (scenario IH), we find that first-period prevention is higher so as to reduce the probability of incurring higher costs in the second period. Similarly, cleanup after an accident in the first period should be somewhat higher due to the effect on environmental harm in the second period.
3 Strict liability

3.1 Analysis of the standard rule

Under strict liability, the firm has to compensate harm irrespective of its prevention behavior. Following Polinsky and Shavell (1994), we assume that the level of compensation due is equal to effective harm \( D_i \), such that the firm has an incentive to utilize cleanup.

In the second period, the firm seeks to

\[
\min_{x_i, c_i} IC^{SL}_2 = x_i + p(x_i)D_i \tag{14}
\]

where \( i = a \) after a first-period accident and \( i = n \) after no accident. For a given level of \( c_0 \), second-period levels care and cleanup activities stem from conditions analogous to (8)-(11). This reflects that the injurer internalizes all repercussions from the choice of prevention and cleanup in the second period and thus will select optimal levels contingent on the level of harm remaining \( h(c_0) \) (and thus first-period cleanup \( c_0 \)). As a result, we obtain \( x_n^{SL} = x_n^* \), \( c_n^{SL} = c_n^* \), \( x_a^{SL} = x_a^*(c_0) \), and \( c_a^{SL} = c_a^*(c_0) \). Thus, depending on whether or not an accident occurred in the first period, the second period expected costs are \( E_a^*(c_0) \) and \( E_n^* \), respectively.

In the first period, the firm expects to produce in period 2 only with probability \( \gamma \). As a result, it will discount payments to be made in the second period with \( \gamma \). The firm seeks

\[
\min_{x_0, c_0} IC^{SL}_1 = E_0 + \gamma [p(x_0)E_a^*(c_0) + (1 - p(x_0))E_n^*] \tag{15}
\]

From this, we obtain the first-order conditions for \( x_0 \) and \( c_0 \) using the envelope theorem:

\[
1 = -p'(x_0) [D_0 + \gamma (E_a^*(c_0) - E_n^*)] \tag{16}
\]

\[
1 = -\frac{\partial h(c_0)}{\partial c_0} \left( 1 + \gamma p(x_a^*(c_0)) \frac{\partial H(c_a^*(c_0), h(c_0))}{\partial h} \right) \tag{17}
\]

where

\[
\frac{dE_a^*}{dc_0} = \frac{\partial H(c_a^*(c_0), h(c_0))}{\partial h} \frac{\partial h(c_0)}{\partial c_0}
\]

shows in (17).

The level of the probability \( \gamma \) influences prevention and cleanup incentives in the first period. In equations (16) and (17), the direct effect is a decrease (increase) in the marginal
benefits of first-period prevention and cleanup in scenario IH (DH), when all else is held
equal. The implication for behavior in the second period that runs via the change in the
level of $c_0$ is inconsequential due to the envelope theorem.

We summarize our findings for the private optimum under strict liability in:

**Proposition 2** **Strict liability:** (i) For the scenario IH with increasing harm, the firm
will choose first-period precaution and cleanup that are socially suboptimal (i.e., $x_0^{SL} < x^*_0$
and $c_0^{SL} < c^*_0$) when $\gamma < 1$. (ii) For the scenario DH with decreasing harm, the firm
will choose first-period precaution and cleanup that are socially excessive (i.e., $x_0^{SL} > x^*_0$ and$c_0^{SL} > c^*_0$) when $\gamma < 1$. (iii) Second-period choices are the socially optimal response to the
distorted level of $c_0$.

**Proof.** Relying on the functions derived from the minimization of private costs in period
2, we may derive the claim from the evaluation of

$$\left( \begin{array}{cc} \frac{\partial^2 IC_1^{SL}}{\partial x_0^2} & \frac{\partial^2 IC_1^{SL}}{\partial x_0 \partial c_0} \\ \frac{\partial^2 IC_1^{SL}}{\partial c_0 \partial x_0} & \frac{\partial^2 IC_1^{SL}}{\partial c_0^2} \end{array} \right) \left( \begin{array}{c} dx_0 \\ dc_0 \end{array} \right) = \left( \begin{array}{c} -\frac{\partial^2 IC_1^{SL}}{\partial x_0 \partial c_0} \\ -\frac{\partial^2 IC_1^{SL}}{\partial c_0^2} \end{array} \right) d\gamma. \hspace{1cm} (18)$$

With $\frac{\partial^2 IC_1^{SL}}{\partial x_0 \partial c_0} = 0$ and $\frac{\partial^2 IC_1^{SL}}{\partial c_0 \partial x_0} = 0$, we obtain

$$\frac{dx_0}{d\gamma} = -\frac{\partial^2 IC_1^{SL}}{\partial x_0 \partial c_0} \times \frac{\partial IC_1^{SL}}{\partial c_0} \times \frac{\partial^2 IC_1^{SL}}{\partial x_0^2} \hspace{1cm} (19)$$

$$\frac{dc_0}{d\gamma} = -\frac{\partial^2 IC_1^{SL}}{\partial c_0 \partial x_0} \times \frac{\partial IC_1^{SL}}{\partial x_0} \div \frac{H}{\partial c_0^2}, \hspace{1cm} (20)$$

where $H > 0$ is the determinant of the Hesse matrix and

$$\frac{\partial^2 IC_1^{SL}}{\partial x_0 \partial c_0} = p'(x_0) [E^*_a(c_0) - E^*_n] \hspace{1cm} (21)$$

$$\frac{\partial^2 IC_1^{SL}}{\partial c_0 \partial x_0} = p(x^*_a(c_0)) \frac{\partial H(c^*_a(c_0), h(c_0))}{\partial h} \frac{\partial h(c_0)}{\partial c_0}. \hspace{1cm} (22)$$

We thus obtain $\frac{dx_0}{d\gamma} > 0$ when $E^*_a(c_0) > E^*_n$ and vice versa. Moreover, we find that $\frac{dc_0}{d\gamma} > 0$ when $\frac{\partial H(c^*_a(c_0), h(c_0))}{\partial h} > 0$ and vice versa. \(\blacksquare\)

Standard strict liability induces inefficient first-period choices. The cause of the ineffi-
ciency is the probability $(1 - \gamma)$ that represents the possibility that the firm may no longer
be active after the first period has elapsed. This is principally related to the disappearing defendant problem which is a context where a damages multiplier can correct incentives (as argued in Polinsky and Shavell 1994, for instance). In the next section, we will elaborate on the potential of a damages multiplier in the present context.

3.2 Potential of a damages multiplier

In order to obtain efficient first-period behavior, the additional policy instrument must take into consideration the departure of private marginal incentives from social ones with respect to both prevention and cleanup. The use of a damages multiplier for first-period environmental harm may change prevention and treatment incentives towards the first-best level, but it cannot induce efficient behavior.

To show this consider (6) and (16), and note that there exists a damage multiplier $\lambda > 0$ to be used under strict liability that satisfies

$$D_0^* + \lambda h(c_0^*) + \gamma (E_a^*(c_0^*) - E_n^*) = D_0^* + (E_a^*(c_0^*) - E_n^*),$$

(23)

where the right-hand side comes from the first-order condition of the social planner. As is clear from (23), the appropriate level of $\lambda$ that induces $x_0^*$ will generally be a function of $c_0$.

When $c_0^*$ can be induced under strict liability, we can rearrange (23) to

$$\lambda = (1 - \gamma) \frac{E_a^*(c_0^*) - E_n^*}{h(c_0^*)}.$$

(24)

In scenario IH, we obtain that $\lambda > 0$ such that the compensatory requirement after an accident in the first period is punitive as $1 + \lambda > 1$. In scenario DH, we obtain that $\lambda < 0$ such that the compensatory requirement after an accident in the first period falls short of the level of harm incurred. By comparing conditions (7) and (17), we can derive a damage multiplier $\theta > 0$ to be used under strict liability that satisfies

$$(1 + \theta) + \gamma p(x(a^*(c_0))) \frac{\partial H(c_0^*(c_0), h(c_0))}{\partial h} = 1 + p(x(a^*(c_0))) \frac{\partial H(c_0^*, h(c_0^*))}{\partial h}$$

(25)

at $c_0 = c_0^*$ that induces $c_{SL}^* = c_0^*$. The multiplier that induces first-best cleanup is given by

$$\theta = (1 - \gamma) p(x(a^*(c_0))) \frac{\partial H(c_0^*, h(c_0^*))}{\partial h}.$$

(26)
It must be remembered (using (2) and (4)) that
\[
\frac{\partial (E_a - E_n)}{\partial h} = p(x_a) \frac{\partial H(c_a, h(c_0))}{\partial h}
\]

such that
\[
E_a^*(c_0) - E_n^* = \int_0^{h(c_0)} p(x_a) \frac{\partial H(c_a, h(c_0))}{\partial h} dh.
\]

From this, we have that \( \lambda \neq \theta \) when the level of \( H \) is not proportional with \( h \) and that \( \lambda < \theta \) when \( \partial^2 H/\partial h^2 > 0 \) in scenario IH and when \( \partial^2 H/\partial h^2 < 0 \) in scenario DH.

Since we generally have that \( \lambda \neq \theta \), we find that a damages multiplier cannot induce first-best choices.

### 3.3 Discussion of other policy options

The inefficiency comes about due to the probability that the first-period firm will no longer be active in the second period. In that eventuality, the first-period firm shifts disadvantages in scenario IH (advantages in scenario DH) to the second-period firm. It may be argued that the first-period injurer contributed to the level of harm in the accident state in the second period. The extent of this contribution may be measured by \( H(c, h) - H(c, 0) = H(c, h) - h(c) \). It is important to note that the inefficiency described cannot be alleviated by giving the second-period injurer the opportunity to claim \( H(c, h) - h(c) \) from the first-period injurer because this will adversely impact incentives in the second period which in turn distort first-period incentives.

The use of a damages multiplier cannot induce first-best choices. Combining a subsidy for cleanup in combination with a damages multiplier or the use of two different subsidies can lead to the efficient outcome. However, as emphasized by Shavell (2011), for example, such subsidies may not be possible when there are different types (e.g., with respect to the harm functions) that cannot be observed by the policy maker.

There may be circumstances in which the first-period injurer will fully internalize the repercussions even with standard strict liability. That may arise when the first-period injurer produces on land that may become contaminated from producing. When the firm prefers to discontinue its operation at the end of the first period, it is thinkable that the price
obtainable for the piece of land fully reflects the implications of the cleanup chosen after an accident in period 1. However, this possibility poses demands regarding the information of potential buyers and regarding the way that the price of the land reacts to its state.

4 Negligence

4.1 Analysis of the standard rule

Under negligence, the firm faces behavioral obligations such that compliance with these standards relieves the firm from the duty to compensate harm caused. It is obvious that leaving harm uncompensated will threaten firm’s cleanup incentives. As a result, we assume that the standards of behavior include a standard of care and a standard of cleanup.

In period 2, we assume that the firm faces behavioral standards given by either \( x^*_n \) and \( c^*_n \) or \( x^*_a(c_0) \) and \( c^*_a(c_0) \), that is, standards of conduct are equal to the socially optimal levels of prevention and cleanup for the applicable state of the world. Denoting in state \( i \) \( T_i = x_i + p(x_i)c_i, i = a, n \), the firm seeks to minimize private costs

\[
IC^N_{2i} = \begin{cases} 
T_i & \text{if } x_i \geq x^*_i \text{ and } c_i \geq c^*_i \\
E_i & \text{otherwise} 
\end{cases}
\]  

(29)

The second line of (29) would be minimized at \( x^*_i \) and \( c^*_i \) such that obeying the standards of conduct is clearly preferable for the firm in the second period. This is a direct consequence of \( x^*_i \) and \( c^*_i \) being the levels that minimize social costs in state \( i \). In period 2, the standard-obedient firm will thus incur costs \( T^*_a(c_0) = x^*_a(c_0) + p(x^*_a(c_0))c^*_a \) when there was an incompletely cleaned-up accident in period 1 and \( T^*_n = x^*_n + p(x^*_n)c^*_n \) when there was no such accident. For the level of costs in the accident state, we have that

\[
\frac{dT^*_a}{dc_0} = \frac{dx^*_a}{dc_0} [1 + p'(x^*_a)c^*_a] + p(x^*_a)\frac{dc^*_a}{dc_0},
\]

(30)

that is, they are a function of cleanup in the first period because the standards respond to variations in the level of harm remaining. Since the level of \( x^*_a \) solves \( 1 + p'(x^*_a)D^*_a = 0 \), we know that \( 1 + p'(x^*_a)c^*_a > 0 \). By application of Lemma 1, we obtain that:

\footnote{The contribution by Polinsky and Shavell (1994) focuses on strict liability.}
**Lemma 2** The level of costs that a standard-obedient firm incurs in the second period after an accident in the first period is decreasing with first-period cleanup \(dT_a^*/dc_0 < 0\) in scenario IH and increasing \(dT_a^*/dc_0 > 0\) in scenario DH.

In period 1, the firm chooses prevention \(x_0\) and cleanup \(c_0\) to minimize the cost function given by

\[
IC_1^N = \begin{cases} T_0 + \gamma[p(x_0)T_a^*(c_0) + (1-p(x_0))T_n^*] & \text{if } x_0 \geq x_0^* \text{ and } c_0 \geq c_0^* \\ E_0 + \gamma[p(x_0)T_a^*(c_0) + (1-p(x_0))T_n^*] & \text{otherwise} \end{cases}
\]  

(31)

where \(T_0 = x_0 + p(x_0)c_0\). The minimum of the first line of (31) will most likely be reached at \(x_0^*\) and \(c_0^*\). The marginal effects for \(x_0 \geq x_0^*\) and \(c_0 \geq c_0^*\) are written

\[
\frac{\partial IC_1^N}{\partial x_0} = -1 - p'(x_0) [c_0 + \gamma(T_a^* - T_n^*)]  
\]

(32)

\[
\frac{\partial IC_1^N}{\partial c_0} = -1 - \gamma \frac{dT_a^*}{dc_0}  
\]

(33)

When compared to the conditions that yield \(x_0^*\) and \(c_0^*\) (i.e., (6) and (7)), we have the possibility of going out of business (represented by \(\gamma < 1\)) and that the agent need not compensate the level of environmental harm in the first \((c_0 < D_0)\) and the second period \((T_a^* - T_n^* < E_a^* - E_n^* \text{ in scenario IH})\).

The minimization of the second line of (31) for the cases (i) \(x_0 < x_0^*\) and \(c_0 < c_0^*\), (ii) \(x_0 \geq x_0^*\) and \(c_0 < c_0^*\), or (iii) \(x_0 < x_0^*\) and \(c_0 \geq c_0^*\) gives marginal effects

\[
\frac{\partial IC_1^N}{\partial x_0} = -1 - p'(x_0) [D_0 + \gamma(T_a^* - T_n^*)]  
\]

(34)

\[
\frac{\partial IC_1^N}{\partial c_0} = -1 - \frac{\partial h(c_0)}{\partial c_0} - \gamma \frac{dT_a^*}{dc_0}  
\]

(35)

Relative to the marginal effects in (32) and (33), incentives for \(x_0\) and \(c_0\) are stronger since \(D_0\) is relevant instead of \(c_0\) only. It is clear that these marginal effects are equal to zero at choices different from first-best levels. Moreover, since the repercussions for costs in the second period depend upon how \(H\) is affected by harm remaining, we obtain departures from the first-best outcome that depend on whether scenario IH or DH applies.
Negligence is characterized by a discontinuity at the standards of behavior. This may make it privately optimal to obey them. This will result when

\[ T_0^* + \gamma [p(x_0^* T_a^* (c_0^*) + (1 - p(x_0^*))T_n^*] \leq E_0^N + \gamma [p(x_0^N T_a^* (c_0^N) + (1 - p(x_0^N))T_n^*] \]  

where we denote the levels that set (34) and (35) equal to zero by \( x_0^N \) and \( c_0^N \). The right-hand side of (36) increases at a faster pace with \( \gamma \) such that the inequality will (not) hold for \( \gamma \) close to one (zero). From this, we can argue that there is a critical level of \( \gamma \) that is implicitly defined by

\[ \gamma_c = \frac{T_0^* - E_0^N}{[p(x_0^N T_a^* (c_0^N) + (1 - p(x_0^N))T_n^*) - [p(x_0^N T_a^* (c_0^N) + (1 - p(x_0^N))T_n^*]} \]  

We summarize our findings for the private optimum under negligence in:

**Proposition 3** Firms subject to negligence choose second-period behavior that is the socially optimal response to the level of \( c_0 \), as they obey the standards defined at socially optimal levels. In the first period, firms choose socially optimal behavior (i.e., standard obedience) when the probability \( \gamma \) is sufficiently high.

### 4.2 Potential of a damages multiplier

We argued that the potential for a damages multiplier for inducing the first-best outcome was limited under strict liability. The fundamental reason was that the marginal incentives for two different kinds of behavior needed correction such that a single policy instrument did not suffice.

Under negligence, the injurer faces a cost function with a discontinuity and a damages multiplier can help to make compliance with the standards clearly preferable. There is no need to engineer the instrument such that private marginal incentives match social marginal incentives. As a result, a sufficiently high multiplier will be able to ensure first-best behavior.

### 4.3 Discussion of cause-in-fact negligence rule

It is clear from the argumentation above that not only the capability of the standard negligence to induce the first-best levels of prevention and cleanup but also the attractiveness of
the damages multiplier under negligence rests on the assumption that there is a discontinuity in the firm’s cost function.

When we instead consider the practically very relevant case of having liability only for the harm caused by the negligence in the sense of Kahan (1989), for example, the first-period incentives are distorted and the appeal of the damages multiplier is only as high as it was under strict liability. Firms arrive at privately optimal behavior by considering how their costs change with the two variables of interest and the level of harm with non-negligent behavior simply vanish as they are fixed components of the cost function.

Specifically, in period 2, the cost function is

\[ IC_{2i}^{NC} = x_i + p(x_i)D_i - p(x_i^*(c_0))H_i^*(c_0) \]

and is minimized by the choice of the behavioral standards. In period 1, we then obtain

\[ IC_{1i}^{NC} = E_0 - p(x_0)h(c_0) + \gamma[p(x_0)T^*_a(c_0) + (1 - p(x_0))T^*_n], \]

which leads to the marginal incentives explicated in (34) and (35). As both kinds of first-period behaviors differ from their first-best levels and modifications of marginal incentives are key for the correction, we would then again find that a simple damages multiplier will not induce the first-best outcome.

5 Conclusion

This paper addresses the realistic scenario in which the level of harm in the current period may depend on the occurrence and cleanup of previous accidents. For example, it will often be true that a prior environmental disaster exacerbates the repercussions of a given environmental accident. We have shown that strict liability cannot induce first-best incentives whenever injurers assign some positive probability of not being the injurer the next time around. The inadequate incentives cannot be remedied by a damages multiplier because two behavioral dimensions are concerned. Under negligence implying a discontinuous injurer cost function, first-best choices may result and can be ensured by relying on a simple damages
multiplier. Under negligence with a cause-in-fact requirement, negligence no longer performs strictly better than strict liability.

Our contribution is – to the best of our knowledge – the first to consider the performance of environmental liability rules when harm is cumulative. Future work may consider more general setups and relate to further possibilities of addressing the problem (e.g., by elaborating on how a combination of regulation and liability may perform when there are information asymmetries). We have considered the context of environmental harm, but applications outside of this domain (e.g., with respect to medical treatment) may also be important.
References


