Precision and Manipulation of Non-Financial Information: The Case of Environmental Liability

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Precision and Manipulation of Non-Financial Information: The Case of Environmental Liability

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Abstract

The disclosure of non-financial information, including environmental information, has become more important in recent years. Nevertheless, the theoretical literature has mainly focused on the incentives of when and how to disclose financial information. This paper analyzes the manager’s incentives for the precise measurement and fair disclosure of environmental pollution levels, given that this information can be used to make shareholders liable for environmental damages.

It transpires that the liability regime matters. (1a) Under strict liability, neither the shareholders nor the manager are interested in the precise measurement of environmental pollution. (1b) In contrast, under a negligence rule, the precision of the pollution indicator becomes important because shareholders are only held liable for excessively high pollution levels. Higher precision of the pollution indicator reduces Type I errors and, in turn, increases the manager’s compensation. (2a) If the manager is able to manipulate reported pollution levels and this manipulation is not observable, the real pollution level will increase. Under strict liability, shareholders suffer from this activity because of higher damage compensation. (2b) Under a negligence regime, the manager will manipulate environmental pollution reports more the more precise the measurement technique gets. Shareholders now benefit from pollution report manipulation since it is easier to escape liability; the more so the higher the expected damages are.

Overall, while a negligence regime encourages more precise pollution measurement than strict liability, it also provides stronger incentives for manipulation. The paper adds to the environmental disclosure literature by showing that the incorporation of liability rules may imply a non-monotonic association between environmental performance and environmental disclosure.
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1. Introduction

In recent years, the disclosure of non-financial information has become more important (e.g. Perez-Batres et al. 2012; Cormier and Magnan 2015; Guenther et al. 2016). While financial information is primarily used by investors and lenders, non-financial information is addressed to additional stakeholders, including, e.g. consumers, employees or the general public. In addition, the institutional environment associated with non-financial information might differ from that of financial information. For instance, environmental liability rules are unlikely to drive the disclosure incentives for financial information. However, environmental liability rules may affect the manager’s disclosure incentives on environmental reporting, given that this information can be used to make shareholders liable for environmental damages. This paper analyzes how the environmental liability regime affects managers’ incentives (1) to precisely measure and (2) to truthfully report the environmental pollution level and, by that, (3) to effectively reduce pollution, given that there is a separation of ownership and control.

There are many forms of environmental pollution, such as water pollution, soil contamination and air pollution. The reduction of pollution is a pressing goal on the political agenda\(^1\) and environmental liability has become an important instrument to reach this goal.\(^2\) Companies are liable for pollution in many countries, such as in most European countries and in the U.S.

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\(^1\) In the European Union, both countries and companies are required to reduce GHG emissions by at least 20% by 2020 in comparison to 1990 levels (EC 2015).

\(^2\) Other approaches to reducing pollution are bans or regulated trade on pollution certificates. For example, the goal of the European Emission Trading Scheme (EU ETS) is to reduce GHG emissions in the EU (EU 2017).
Liability legislation may require courts to be able to observe the *real* pollution level. However, courts may find it hard to do so (Goldsmith and Basak 2001). For instance, with regard to greenhouse gas (GHG) emissions, there is only limited precision of technical measurement tools (IPCC 2006) and considerable discretion is given to companies on how to measure GHG emission levels (EC 2012a, 2012b). There are also problems of proper verification. Thus, even though European regulation has required GHG emissions to be monitored and reported since 2008 (European Parliament 2003: EU Directive 2003/87/EC), there is still considerable discretion.³

Our model addresses two components of discretion with regard to environmental reporting quality: the *precision* of measuring environmental pollution, which is likely to influence the precision of reporting even if manipulation is not possible or does not take place. The second component addresses the incentives for reporting manipulation. While precision refers to the incentives to improve the accuracy of technical measurement devices in order to reduce the measurement error (reduce the standard deviation), manipulation refers to the manager’s incentives to report lower pollution levels than they actually are (shifting the mean).

We analyze how one important factor of the institutional setting – environmental liability rules – affect the precision and manipulation of pollution reports. There are three scenarios: (1) no liability for environmental pollution, (2) strict liability and (3) a negligence rule. With strict liability, the company – effectively, the company’s shareholders – is held liable when pollution causes damages. With a negligence regime, the company is held liable if pollution cause damages and, *additionally*, if it acted negligently, i.e. if the company failed to meet the “standard of due

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³ For instance, there is discretion due to the principle of “reasonable costs”: “improvements from greater accuracy shall be balanced against the additional costs” (EC 2012b, Art. 8). Moreover, there are options regarding calculation factors. On the one hand, default values are given in the form of reference values, often referring to IPCC guidelines (cf. EC 2012b, Annex VI), but on the other hand, Annex II grants several options for some tiers when determining the calculation factors, often permitting uncertainties of ± 10% (EC 2012b, Annex II).
care” according to legal rules. Courts decide on whether the standard of due care has been met based on the company’s pollution report. In the European Union, companies generally face strict liability (see Directive 2004/35/CE). Still, as we intend to provide a normative analysis, we will also investigate the cases of no liability and of a negligence rule; the latter regime is applied, e.g. in the U.S.

In reality, it is the company’s management which decides not only on the pollution level, but also on reporting. Thus, we explicitly consider the agency problem between shareholders and managers. Only managers are able to observe the real pollution level. Shareholders, however, may have to pay any damage payments. As a result, shareholders rationally set up a compensation contract which provides monetary rewards to the manager not only to increase financial performance, but also environmental performance, that is, to decrease pollution levels. The manager can increase both types of performance by higher respective effort levels. Neither effort level is, however, observable, and is thus not contractible. Instead, the compensation contract is based on a financial and an environmental performance measure, both of which are biased.

We find that the liability regime strongly influences the incentives for pollution measurement precision, pollution report manipulation and real pollution levels. With no liability, pollution levels do not matter such that they are not part of the compensation contract. There is no need for precision or for manipulation, and pollution levels are high.

Under strict liability, shareholders will attempt to reduce pollution to an efficient level and – assuming that reporting manipulation is not possible – the manager will do just that. Neither the shareholders nor the manager are interested in pollution measurement precision. However, if the manager is able to manipulate the pollution report, she will do so and the real pollution level will increase. Shareholders suffer from this activity because of higher damage compensation. Without the separation of ownership and control, manager-shareholders would have no interest in manipulating the pollution report.
Under a negligence rule, the precision of the pollution indicator matters, because shareholders are only held liable for reported pollution levels exceeding the standard of due care. Higher precision of the pollution indicator reduces Type I errors – reported pollution is high even though real pollution is low – and, in turn, this increases the sensitivity of the manager’s compensation to the environmental performance indicator. This is in line with seminal findings of Holmström and Milgrom (1991) and Feltham and Xie (1994), which showed that linking compensation to performance measures works better the less noisy the performance measure is. However, if the manager is able to manipulate the pollution report, she will be more inclined to do so when measurement precision is high. The simple reason for this is that manipulation pays off most when it is the only reason for biased pollution reports. In contrast to a strict liability regime, shareholders now benefit from pollution report manipulation since it is easier to meet the standard of due care and escape liability; the more so the higher the expected damages are.

To sum up, there is a trade-off: while only a negligence regime induces the company to precisely measure pollution levels, it also provides incentives to both the manager and the shareholders to manipulate pollution reporting. It might be an interesting insight for both academics and policy-makers that the incentives for measurement precision and pollution report manipulation crucially depend on the liability regime.

To the best of our knowledge, this paper is the first one to analyze the delicate interaction between environmental liability rules and pollution reporting incentives. It contributes to three different strands of literature. First, the paper adds to the literature regarding reporting precision and reporting manipulation (e.g. Beyer et al. 2010; Ewert and Wagenhofer 2011). Our paper adds to this literature by explicitly addressing the manager’s incentives for precise measurement and fair disclosure of non-financial information, in our case on environmental pollution. Ewert and Wagenhofer (2011) posit that the institutional setting influences reporting incentives. We indeed
find that the particular environmental liability rule affects the manager’s reporting precision incentives. \textsuperscript{4} Similar to Kanodia (2006) and Kanodia and Sapra (2016), we address real effects of reporting. Yet, while Kanodia and Sapra (2016) emphasize the real effects of financial information on investment efficiency, risk management strategies and spillover effects in the banking sector, our paper shows the effect of non-financial information on real environmental pollution.

Second, the paper contributes to the literature that addresses the link between environmental performance and environmental disclosure. \textsuperscript{5} Li et al. (1997) have presented a partial disclosure equilibrium model showing that companies with sufficient environmental performance will truthfully report environmental liabilities while poorly performing companies will not if there is uncertainty on the existence and size of environmental liabilities created, or if outside stakeholders can impose political (proprietary) costs, such as litigation costs. Stakeholder theory, however, suggests that poor environmental performers face more political and social pressures, which induces them to increase discretionary environmental disclosure (Patten 2002). The empirical evidence on the association between environmental performance and environmental disclosure is mixed (Clarkson et al. 2008). We contribute to this discussion in three ways. First, we differentiate between measurement precision and report (non-)manipulation as determinants of environmental reporting quality. Second, we explicitly incorporate the environmental liability regime and the agency relationship between the manager and shareholders, and thereby endogenize the

\textsuperscript{4} Except for some auditing papers, the theoretical literature does not explicitly address the link between liability rules and measurement precision. For example, in Göx and Wagenhofer (2010), reporting precision is affected by whether a signal indicates a low or high value of the asset which is used as collateral in debt contracting.

\textsuperscript{5} Other environmental reporting literature is rather empirical, ignoring the impact of the environmental liability regime on reporting choices (e.g. Deegan and Gordon 1996; Cormier et al. 2005; Kolk et al. 2008; Sullivan and Gouldson 2012; Stanny 2013; Matisoff et al. 2013; Lu and Abeysekera 2014; Matsumara et al. 2014; Clarkson et al. 2015; Griffin et al. 2017).
shareholders’ expected liability costs, which are exogenous in the Li et al. (1997) model. Third, we find that, under a negligence regime, the association between environmental performance and measurement precision is non-monotonic, which is consistent with the ambiguous evidence cited above.

We are not aware of any financial accounting literature that links a company’s choices regarding reporting quality to liability regimes. In the auditing literature, however, it is well known that the specific characteristics of auditor liability significantly affect audit quality (e.g. Schwartz 1997; Willekens and Simunic 2007; Laux and Newman 2010; Bigus 2015; Moroney and Trotman 2016). We assume the shareholders to be held liable while the agent (manager) is not liable, whereas the auditing literature assumes the agent to be held liable and the shareholders not. In reality, the “business judgment rule” makes it difficult to make the manager responsible (e.g. Reinhardt et al. 2008; Bricker 2013; Told 2015).

Finally, we contribute to the law and economics literature, which has not yet analyzed how liability rules affect the manager’s incentives for measurement precision and reporting manipulation (e.g. Schäfer and Ott 2004; Shavell 2007; Endres et al. 2015). One paper by Polinsky and Shavell (2012) is more closely related to our research question. They analyzed what type of disclosure regime – either voluntary or mandatory disclosure – regarding product risks is socially beneficial. They find that mandatory disclosure rules are more valuable to customers, while the firm’s incentives to acquire information are stronger under voluntary disclosure. However, Polinsky and Shavell (2012) ignore the idea of owner-manager conflicts of interest and do not address measurement precision or reporting manipulation.

In the following paper, Section 2 describes the model. Section 3 addresses solely the incentives for measurement precision. Section 4 extends the analysis to pollution report manipulation. Section 5 concludes the paper.
2. Model assumptions

We analyze a two-stage model with risk-neutral actors and a zero discount rate for riskless assets. The shareholders (principal) of a polluting company delegate two tasks to a professional manager (agent): exerting high effort in order to maximize shareholder value and deciding on the pollution level. For simplicity, we assume that reducing the pollution level does not compete with the core business operation task to maximize shareholder value. Even though we do not need the manager’s core business activity to derive the main results, we keep it in the model because managers are not paid only for environmental performance.\(^6\) We assume that the manager suffers a disutility from reducing pollution, e.g. induced by foregone leisure time, or because she does not like the task, or because more pollution reduction is more costly and reduces the manager’s budget.

The shareholders (and other parties, such as courts) are unable to directly observe or to control the managerial effort to maximize shareholder value and to influence the pollution level. The manager’s disutilities from reducing pollution and from carrying out the core business activity are not verifiable. As a consequence, the court is unable to infer \textit{ex post} the pollution level induced by the compensation contract. In order to keep the model simple, those are the only information asymmetries; everything else is assumed to be common knowledge.

In order to align their interests, shareholders offer a compensation contract based on verifiable indicators for financial performance and for environmental performance (FPI and EPI), which we call \(\tilde{x}\) and \(\tilde{y}\), respectively, both of which are stochastic variables. Following the literature, we assume linear compensation contracts (Holmström and Milgrom 1991; Feltham and Xie 1994).

\(^6\) In Appendix A8 we allow for a binding capacity constraint that connects both tasks via a reaction function. It turns out that the qualitative results on the effects of the different liability regimes do not change.
The FPI, \( \tilde{x} \), such as a stock price, depends on the manager’s effort to carry out core business operations \( b \) and is uniformly distributed, \( \tilde{x} \sim \text{uniform}(b - \pi, b + \pi) \), with \( b \geq \pi \geq 0 \) and an expected value of \( E[\tilde{x}] = b \). Analogously, the EPI \( \tilde{y} \) depends on the manager’s decision \( e \) with regard to the pollution level. The EPI \( \tilde{y} \) is also uniformly distributed\(^8\): \( \tilde{y} \sim \text{uniform}(e - \epsilon, e + \epsilon) \), with \( e \geq \epsilon \geq 0 \) and an expected value \( E[\tilde{y}] = e \). Both the FPI and the EPI must be disclosed.

The distribution parameter \( \epsilon \) can be interpreted as the measurement error of the company’s pollution level. As explained above, the nature of environmental pollution makes its precise measurement very challenging. Since neither the company’s reported pollution level nor the optimal pollution level defined by law can be negative, we consistently assume \( e^* \geq \epsilon \geq 0 \) and \( e_{opt} \geq \epsilon \geq 0 \), respectively. We will derive \( e^* \) and \( e_{opt} \) below.

**TABLE 1: Manager’s tasks**

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Performance indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>( b ) – manager’s effort to carry out core business operations</td>
<td>( \tilde{x} ) – financial performance indicator, ( \tilde{x} \sim \text{uniform}(b - \pi, b + \pi) ), ( E(\tilde{x}) = b )</td>
</tr>
<tr>
<td>( e ) – absolute level of the company’s environmental pollution, ( 0 \leq e \leq e_{max} )</td>
<td>( \tilde{y} ) – environmental performance indicator, ( \tilde{y} \sim \text{uniform}(e - \epsilon, e + \epsilon) ), ( E(\tilde{y}) = e )</td>
</tr>
</tbody>
</table>

Both the FPI \( \tilde{x} \) and EPI \( \tilde{y} \) are verifiable and thus, contractible. In order to focus on the environmental performance indicator, we assume that the manager is unable to manipulate \( \tilde{x} \). In the basic model, the manager truthfully reports the environmental performance indicator \( \tilde{y} \).

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\( ^7 \) There is some evidence for a positive relation between a company’s financial and environmental performance (e.g. Qian and Xing 2016; Gonenc and Scholtens 2017), but also mixed evidence (e.g. Horváthová 2012; Delmas et al. 2015; Trumpp and Guenther 2015). Introducing a link of the form of \( E[\tilde{x}] = b + ke \), where \( k \) is either greater or smaller than 0, does not affect the qualitative results. See Appendix A10 for more details.

\( ^8 \) With uniform distributions, we obtain closed-form solutions. Nevertheless, the numerical results that we obtain under normally distributed performance indicators are qualitatively the same. See Appendix A9 for more details.
The manager’s decision on pollution affects the level of future expected environmental damages. If the manager does nothing to reduce the environmental pollution level, it reaches its maximum level $e_{\text{max}}$, and expected future damages are then $ED = p(e = e_{\text{max}})D = D$. We define $p(e) = e/e_{\text{max}}$. If there is some effort to reduce pollution, future expected damages amount to $ED = p(e)D = (e/e_{\text{max}})D$. With no pollution, $e = 0$, no damage is expected. Depending on the liability setting, the company may be held liable for environmental damages.

In the absence of environmental liability, the shareholders’ and the manager’s respective utility functions are reflected by the following (see also Segerson and Tietenberg 1992):

$$U^P = \bar{x} - s(\bar{x}, \bar{y})$$

$$U^M = s(\bar{x}, \bar{y}) - \frac{1}{2}c_b b^2 - \frac{1}{2}c_e(e_{\text{max}} - e)^2$$

The shareholders’ utility, $U^P$, is defined by the financial performance of the company less the manager’s remuneration, $s$, which depends on the performance measures $\bar{x}$ and $\bar{y}$. The manager’s utility, $U^M$, is defined by her salary, $s$, which is based on the indicators for financial and environmental performance minus the disutilities for her effort regarding core business operations and for her effort to reduce pollution below the maximum level $e_{\text{max}}$. The disutilities are each assumed to depend quadratically on the particular effort and are expressed in monetary terms by the disutility parameters $c_b$ and $c_e$, respectively. It is important to keep in mind that the court is unable to verify either disutility. Without loss of generalization, we assume that the manager has a zero reservation wage.

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9 Environmental damages usually take effect after a considerable time delay, see Segerson and Titenberg (1992).

Discounting future damages with a positive discount rate does not change qualitative results.
In order to obtain interior solutions, we assume the manager’s disutility to be convex and that her disutility when avoiding any pollution exceeds maximum expected damages, \( \frac{1}{2}ce_{max}^2 > p(e = e_{max})D = D \). Otherwise, zero pollution would be socially desirable.

**Reporting manipulation.** In Section 4, we introduce a third activity of the manager at \( t = 1 \), specifically pollution report manipulation (or reporting manipulation for short), indicated by \( i \). Higher levels of pollution report manipulation tend to lower reported pollution:

\[
E[\hat{y}] = e - i. \tag{2}
\]

We assume \( i \) to be unverifiable, with \( 0 \leq i \leq e \).\(^{10}\) Contracts can still only be made based on the EPI \( \hat{y} \) or FPI \( \hat{x} \). Otherwise, there is symmetric information.

There is evidence that companies suffer negative economic consequences when their disclosure on environmental issues does not match environmental performance (greenwashing).\(^ {11}\) We therefore assume in Section 4 that the company’s expected reputation losses increase with the extent of pollution report manipulation (Cao et al. 2012).

\[
R \cdot \frac{i}{e_{max}} = r \cdot i \tag{3}
\]

where \( R \) is the maximal future reputation loss.

\(^{10}\) Consequently, we also adjust the assumption on the measurement error: \( e - i \geq \varepsilon \geq 0 \).

\(^{11}\) Lyon and Montgomery (2015, 225) broadly define greenwashing as “a range of communications that mislead people into adopting overly positive beliefs about an organization’s environmental performance,” which is consistent with our definition of environmental reporting manipulation. There is evidence that greenwashing has direct negative effects on the company’s financial performance (Walker and Wan 2012; Wu and Shen 2013), but also reduces the consumer’s product evaluation (Chang 2011).
Figure 1: Timeline of events

We analyze how strict liability and a negligence rule affect the manager’s choice to precisely measure and to correctly report pollution levels. With strict liability, the company, that is, the company’s shareholders, is held liable whenever environmental pollution causes damages. The company has sufficient assets to pay damages. The manager is not held liable. This assumption is realistic due to the “business judgment” rule and the fact that manager’s assets are usually limited, but makes socially optimal contracts infeasible in our setting. With a negligence regime, the company is held liable if pollution causes damages and, additionally, if the company acted negligently, i.e. if it failed to meet the “standard of due care” as specified by legal rules. We follow the law and economics literature and assume that the standard of due care is defined by the socially optimal emission level, which we will derive in the following section. The court decides on whether due care has been met based on the company’s verifiable pollution report, $\tilde{y}$.

We also assume that victims face zero transaction costs when bringing a lawsuit (Shavell 2007). If transactions costs were too high, victims would not sue and, consequently, shareholders and the manager would not care about pollution levels in the first place.

12 Environmental law in the European Union defines the liability of the company, not of the management (see 2004/35/CE, Art. 8). In principle, corporation law allows shareholders to ask managers for damage compensation if they violated their duties towards shareholders. However, the “business judgment” rule makes it difficult to hold managers liable (see Reinhardt et al. 2008; Bricker 2013; Told 2015).
3. Model analysis: incentives for pollution measurement precision

For simplicity’s sake, we first focus only on the measurement problem and omit report manipulation, that is $i = 0$. Consequently, reputation losses do not occur either. In the following, we first show the case of no liability and the social optimum as a benchmark. Afterwards, we analyze the impact of strict liability and of a negligence regime.

**No environmental liability**

In the absence of environmental liability, the shareholders maximize utility according to (1a), taking into account the manager’s utility function (1b). The shareholders design a linear compensation scheme $s(\bar{x}, \bar{y}) = \alpha + \beta \bar{x} + \gamma \bar{y}$ and decide how to choose $\alpha$, $\beta$ and $\gamma$ before the manager decides on the action set $(b, e)$. Thus, the shareholders aim to maximize expected utility

$$\max_{\alpha, \beta, \gamma, b, e} E(U)^P = b - E(s(\bar{x}, \bar{y})) = b - (\alpha + \beta b + \gamma e)$$

with respect to the individual rationality constraint (IR), that is the zero reservation wage the manager could receive in alternative employment

$$E(U)^M = \alpha + \beta b + \gamma e - \frac{1}{2} c_b b^2 - \frac{1}{2} c_e (e_{\text{max}} - e)^2 \geq 0$$

and with respect to the two incentive compatibility constraints (IC 1 and IC 2), which ensure that the manager undertakes the activities that maximize her expected utility:

$$\frac{\partial E(U)^M}{\partial b} = 0 = \beta - c_b b^*$$

$$\frac{\partial E(U)^M}{\partial e} = 0 = \gamma + c_e (e_{\text{max}} - e^*)$$

Introducing Lagrange multipliers $\lambda, \mu$ and $\nu$ for each constraint yields the following Lagrange function:
\[ L = b - \alpha - \beta b - \gamma e + \lambda \left( \alpha + \beta b + \gamma e - \frac{1}{2} c_b b^2 - \frac{1}{2} c_e (e_{max} - e)^2 \right) \]

\[ + \mu (\beta - c_b b) + v (\gamma + c_e (e_{max} - e)) \]

Solving this optimization problem yields the results summarized in TABLE 2 (see Appendix A1 as well). The asterisk always marks the individual optimum for the manager’s working effort in the particular scenario.

**TABLE 2: Results with no environmental liability**

<table>
<thead>
<tr>
<th>Environmental pollution level</th>
<th>( e^* = e_{max} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental compensation contract parameter</td>
<td>( \gamma = 0 )</td>
</tr>
<tr>
<td>Expected utility of shareholders</td>
<td>( EU^p = \frac{1}{2} \cdot \frac{1}{c_b} )</td>
</tr>
</tbody>
</table>

The consequence of no environmental liability is that the compensation contract ignores environmental performance; \( s(\bar{x}, \bar{y}) = -(1/2) \cdot (1/c_b) + 1 \cdot \bar{x} = s(\bar{x}) \). Consistently, the manager does not do anything to reduce emission levels, pollution reaches the maximum level \( e_{max} \). Expected environmental damages reach the maximum level \( p(e = e_{max})D = D \).

**The socially optimal pollution level**

The socially optimal emission level is derived by minimizing the expected social cost function \( EC(e) \) (Shavell 2007), which consists of the expected damages from pollution and the manager’s disutility to reduce them:

\[ EC(e) = p(e)D + \frac{1}{2} c_e (e_{max} - e)^2 = \frac{e}{e_{max}} D + \frac{1}{2} c_e (e_{max} - e)^2. \]

Optimization yields (see Appendix A2):

\[ e_{opt} = e_{max} - \frac{d}{c_e} \quad \text{with} \quad d = \frac{D}{e_{max}} > 0. \]
The social optimum is positive, $e_{opt} > 0$, since we assume $(1/2)c_e e_{max}^2 > D$. The socially optimal pollution level decreases with higher damages, $D$, and lower costs to reduce pollution, $c_e$.

**Strict liability**

In this scenario, the company’s shareholders have to pay damages to victims of environmental damages. Damages must be paid regardless of how much the manager tried to reduce the pollution level. The shareholders now also must consider expected damage payments:

$$\max_{a,b,\gamma,b,e} EU_c = b - \alpha - \beta b - \gamma e - p(e)D.$$  \hspace{1cm} (11)

Bear in mind the assumption that the manager is not held liable, that is, her objective function remains unchanged. Lagrange optimization yields the results summarized in TABLE 3.

<table>
<thead>
<tr>
<th>Environmental pollution level</th>
<th>$e^* = e_{max} - \frac{d}{c_e} = e_{opt}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental compensation contract parameter</td>
<td>$\gamma = -d$</td>
</tr>
<tr>
<td>Expected utility of shareholders</td>
<td>$EU_c = \frac{1}{2} \cdot \frac{1}{c_p} - d \left( e_{max} - \frac{1}{2} \frac{d}{c_e} \right)$</td>
</tr>
</tbody>
</table>

The shareholders bear the cost of environmental damages, and thus design the compensation contract in such a way that the manager fully internalizes the damage payments, thus choosing the socially optimal pollution level $e_{opt}$. Therefore, remuneration also depends on the environmental performance indicator $\tilde{y}$. Any increase in $\tilde{y}$ reduces the manager’s compensation.

The expected utility of the shareholders compared to the no liability case decreases by $d(e_{max} - (1/2) \cdot (d/c_e)) > 0$. This expression can be interpreted as a kind of agency cost caused by the introduction of strict liability. The manager is “punished” for increasing pollution.
However, the shareholders need to compensate the manager’s disutility resulting from her pollution-reducing efforts, and thus need to increase the fixed salary parameter, \( \alpha \). This in turn reduces the shareholders’ expected utility.

Another important implication of the results in Table 3 is that the noise of the environmental performance indicator as measured by \( \varepsilon \) is not of interest for any of the players. Under strict liability, measurement precision is not important.

**Negligence rule**

With a negligence regime, the company is held liable if pollution causes damages and, additionally, if the company acted negligently, i.e. if it failed to meet the standard of due care specified by legal rules. We follow the law and economics literature and assume that the standard of due care is defined by the social optimum (Shavell 2007).\(^{13}\) According to (10), the legislator should define a threshold level of the EPI which companies should not exceed:

\[
y_{opt} = e_{opt}
\]  

(12)

Thus, if there is damage, the company only will be held liable if the environmental performance indicator indicates pollution levels greater than \( y_{opt} \). With lower indicated pollution levels, there is no liability. Consequently, the shareholders’ utility function has two sections.

\[
U^p = \begin{cases} 
\bar{x} - s(\bar{x}, \bar{y}) & \text{if } \bar{y} \leq y_{opt} = e_{opt} = e_{max} - \frac{d}{c_e} \\
\bar{x} - s(\bar{x}, \bar{y}) - p(e)D & \text{if } \bar{y} > y_{opt}
\end{cases}
\]

(13)

We first focus on the case that the EPI \( y \) indicates negligence (\( \bar{y} > y_{opt} \)). Recall that the EPI is biased and uniformly distributed between \( e - \varepsilon \) and \( e + \varepsilon \).

\(^{13}\) Otherwise, a negligence rule is likely to induce excessive or suboptimal levels of care to decrease pollution.
Ex ante, the probability that the EPI exceeds the standard of due care $y_{opt}$ amounts to:

$$
P(\hat{y} > y_{opt}) = 1 - P(\hat{y} \leq y_{opt}) = 1 - F(y_{opt}) = 1 - \frac{y_{opt} - (e - \varepsilon)}{2\varepsilon} \geq 0 \quad (14)$$

The expected utility of the shareholders then reads:

$$EU'^{negl} = b - \alpha - \beta b - \gamma e - \frac{e}{e_{max}} D \cdot P(\hat{y} > y_{opt})$$

$$= b - \alpha - \beta b - \gamma e - \frac{e}{e_{max}} D \left(1 - \frac{y_{opt} - e + \varepsilon}{2\varepsilon}\right) \quad (15)$$

Again, Lagrange optimization is applied to derive the results in TABLE 4.

<table>
<thead>
<tr>
<th>Environmental pollution level</th>
<th>$e^* = e_{max} - \frac{d}{2c_e} - \frac{e_{max}d}{2(\varepsilon c_e + d)} \leq y_{opt}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental compensation contract parameter</td>
<td>$\gamma = -c_e(e_{max} - e^*) = -c_e \left(\frac{d}{2c_e} + \frac{e_{max}d}{2(\varepsilon c_e + d)}\right) &lt; 0$</td>
</tr>
<tr>
<td>Expected utility of shareholders</td>
<td>$EU'^{p} = \frac{1}{2} \cdot \frac{1}{c_b} - \frac{c_e}{2} (e_{max} - e^<em>)^2 - d e^</em> \left(\frac{1}{2} - \frac{y_{opt} - e^*}{2\varepsilon}\right)$</td>
</tr>
</tbody>
</table>

Appendix A4 shows that the pollution level $e^*$ is lower than the socially optimal level $e_{opt}$ and lower than the negligence standard $y_{opt}$. Why should the shareholders want the manager to voluntarily reduce the pollution level more than necessary, even though this is costly (due to a higher level of the manager’s disutility)? The answer is: The environmental performance indicator $y$ is not perfect, and might indicate high pollution levels even though real but unverifiable pollution does not exceed the social optimum. This Type I error makes the company liable even though it actually did not do wrong. Since the manager’s compensation decreases with the shareholders’ expected liability payments, the noise in the EPI $\hat{y}$ matters. In accordance with basic principal-
agent literature (e.g. Holmström and Milgrom 1991; Lothe and Myrtveit 2003), we find that the manager’s compensation becomes more sensitive to the EPI the more precise the EPI gets.\(^{14}\)

Lower *real* pollution levels than required by the standard will make it less likely that the EPI will wrongly indicate negligence. The Type I error decreases as well as the damage payments related to it. As long as the reduced expected damage payments exceed the additional managerial costs of reducing real pollution levels, it makes sense to reduce pollution levels below the standard level required by law. Thus, in contrast to strict liability, the negligence rule tends to induce *excessive* care due to the imprecise measurement of real pollution levels.

Reducing real pollution pays off more with a more precise EPI, i.e. with lower values of \(\varepsilon\). With a smaller measurement error, it is more likely that the EPI will correctly reflect lower real pollution and that the shareholders can escape liability. Thus, with smaller measurement error, there will be lower real pollution in equilibrium (see Appendix A5):

\[
\frac{\partial e^*}{\partial \varepsilon} > 0 \quad \text{if } e_{max}, c_e > 0.
\] (16)

The shareholders’ expected utility also increases as measurement error decreases:

\[
\frac{\partial EU^p_{negl}}{\partial \varepsilon} = -\frac{d \cdot e^*}{2 \cdot \varepsilon^2} \cdot (y_{opt} - e^*) \leq 0.
\] (17)

The important insight here is that, in contrast to a strict liability rule, the company’s shareholders have an interest in the higher precision of the environmental performance indicator.

If it is assumed that the measurement error can be reduced and the real pollution level is not too high, there must be a case in which the EPI never indicates negligence. In mathematical terms, we know from (16) that the real pollution level \(e^*\) decreases if the measurement error \(\varepsilon\) decreases.

\(^{14}\frac{\partial \gamma}{\partial e} > 0\), i.e. with smaller \(\varepsilon\) (more precise EPI) \(\gamma\) decreases, but because \(\gamma < 0\) its absolute value increases.
Thus, there is an $\hat{\epsilon}$ below which the associated $\hat{e}^*$ is so small that $\hat{e}^* + \hat{\epsilon} \leq y_{opt}$ holds for sure and, as a consequence, liability can be ruled out. The point when $P(\hat{y} \leq y_{opt}) = 1$ holds determines the threshold $\hat{\epsilon}$ below which liability is ruled out (see Appendix A5):

$$\hat{\epsilon} = -\frac{3d}{4c_e} + \frac{1d}{4c_e} \sqrt{1 + 8\frac{c_e}{d}e_{max}}$$  \hspace{1cm} (18)

Thus, we complement the shareholders’ expected utility function from relation (13) by the non-negligence case and make it dependent on the threshold measurement error $\hat{\epsilon}$.

$$EU^P = \begin{cases} b - \alpha - \beta b - \gamma e & \text{if } \epsilon \leq \hat{\epsilon} \\ b - \alpha - \beta b - \gamma e - d \cdot e \cdot \left(1 - \frac{y_{opt} - e + \epsilon}{2\epsilon}\right) & \text{if } \epsilon > \hat{\epsilon} \end{cases}$$  \hspace{1cm} (19)

The lower part of this utility function has already been analyzed (see (17)). The upper part implies no negligence and the shareholders’ expected utility in equilibrium results in:

$$EU^P_{not \_ negligence} = \frac{1}{2} \cdot \frac{1}{c_b} - \frac{c_e}{2} (e_{max} - e^*)^2 = \frac{1}{2} \cdot \frac{1}{c_b} - \frac{c_e}{2} \left(\frac{d}{c_e} + \epsilon\right)^2$$  \hspace{1cm} (20)

Again, the shareholders’ expected utility increases the more precise the EPI becomes: $\frac{\partial EU^P_{not \_ negligence}}{\partial \epsilon} = -c_e \left(\frac{d}{c_e} + \epsilon\right) < 0$. The reason is the same as before: The lower the measurement error of the EPI $\hat{y}$ is, the less the manager needs to reduce the real pollution level $e^*$ in order to avoid negligence. Thus, the shareholders save the managerial cost of reducing the real pollution. Following this reasoning, shareholders reach the highest expected utility for the most precise pollution report. Then, $\epsilon = 0$ is valid, the real pollution level equals the social optimum, i.e. $e^* = y_{opt}$. Shareholders’ expected utility yields $EU^P_{not \_ negligence, max} = 1/(2c_b) - d^2/(2c_e)$. Analogously, the maximum measurement error, $\epsilon = y_{opt}$, minimizes the shareholders’ expected utility (see TABLE 4):

---

15 Optimization is restricted by the “no negligence constraint” $e^* + \hat{\epsilon} \leq y_{opt}$. In equilibrium, this constraint holds as an equality. See Appendix A5.
EU_{negl,min} = 1/(2c_b) - (de_{max})/2. This minimum expected utility under negligence still exceeds the shareholders’ expected utility under strict liability, \( EU_{strict} = 1/(2c_b) - d(e_{max} - d/(2c_e)) \). The reason is that under a negligence rule there is a chance to escape liability. Figure 2 illustrates both how the shareholders’ expected utility in equilibrium depends on the measurement error of the EPI and also depicts the lower and constant expected utility with strict liability.

**Figure 2:** The shareholders’ expected utility under a negligence rule depending on the measurement error of the environmental performance indicator, \( EU^P(\epsilon) \)

Figure 3 illustrates the relationship between the measurement error of the EPI and the real pollution level \( e^* \) in equilibrium. This relation is non-monotonic. As long as \( \epsilon \) does not exceed the threshold level \( \hat{\epsilon} \), the manager chooses the real pollution level \( e^* \) in a way that liability is ruled out and \( e^* + \epsilon = y_{opt} \) holds.\(^{16}\) Thus, with higher error \( \epsilon \), the real pollution level \( e^* \) decreases in equilibrium. However, if the measurement error exceeds the threshold level \( \hat{\epsilon} \), the manager can-

\(^{16}\) This result stems directly from the assumption of uniformly distributed environmental performance indicators. With normally distributed indicators, liability cannot definitively be ruled out. Still, we obtain similar qualitative results, because even when it is impossible to definitively rule out liability, it becomes very unlikely to be held liable with very precise measurement techniques. See Appendix A9 for more details.
not avoid liability. This changes the incentives to influence the real pollution level. Higher measurement errors reduce the marginal benefit of further real pollution reduction. Note, however, that, due to the measurement error of the EPI, a negligence regime generally induces lower real pollution levels than a strict liability rule, and lower than would be socially optimal.

**Figure 3:** Real pollution levels in equilibrium depending on the measurement error of the environmental performance indicator, $e^*(\varepsilon)$

The non-monotonic association between environmental performance and measurement precision seems to be complement the mixed empirical evidence. While Clarkson et al. (2008) find a positive link between environmental performance and environmental disclosure as suggested by disclosure theory, Patten (2002) reports a negative association according to stakeholder theory. Our model suggests that either association is possible depending on the level of measurement precision of the environmental performance indicator.

**RESULT 1:** Strict liability provides efficient incentives to reduce pollution, but does not induce the manager to precisely measure the pollution level. With a negligence regime, precision of pollution measurement becomes important. With more precise measurement, it is less likely that non-tolerable (negligent) pollution levels are reported even though real pollution is low. Due to this Type I error, the real pollution level is generally lower than the socially optimal pollution level.
4. Model extension: incentives for pollution measurement precision and pollution report manipulation

We now allow for pollution report manipulation, that is \( i > 0 \), and for possible reputation losses due to misreporting. Again, we analyze the incentives for report manipulation under strict liability as well as under negligence. We will distinguish between the subcases where there is a reputation loss and where there is none. We do not analyze the case of no liability, since there is obviously no incentive to manipulate pollution reports in such cases.

**Pollution report manipulation under strict liability**

We adjust the manager’s utility function for the additional disutility related to the reporting manipulation activity.\(^{17}\) Thus, a fourth constraint in the optimization problem has to be considered:

\[
\frac{\partial EU^M}{\partial i} = 0 = -\gamma - c_i i^* \tag{21}
\]

The shareholders need to consider a possible reputation loss. In the absence of reputation losses \((R = 0)\), the resulting manipulation level in equilibrium is positive, \( i^* = d/(c_e + c_i) \). Manipulation pays off more as damage payments increase, and decreases with the cost parameters \( c_e \) and \( c_i \). Since the manager manipulates the reported pollution level \( \tilde{y} \), she is able to raise the *real* pollution level accordingly. Thus, real pollution is higher than in the initial strict liability model.

The shareholders will anticipate reporting manipulation and will reduce the responsiveness of managerial compensation to the EPI. Thus, the absolute value of the compensation parameter \( \gamma \)

\(^{17}\) \( EU^M = \alpha + \beta b + \gamma (e - i) - \frac{1}{2} c_e b^2 - \frac{1}{2} c_e (e_{max} - e)^2 - \frac{1}{2} c_i i^2 \).
is now lower than before.\textsuperscript{18} Compared to the model without manipulation, the shareholders’ expected utility is reduced by \((d/2)\)\(i^*\). The shareholders anticipate that the company’s real pollution \(e^*\) is higher than without manipulation, which results in higher future damage compensation.

TABLE 5: Results with pollution report manipulation under strict liability

<table>
<thead>
<tr>
<th>Shareholders’ objective function</th>
<th>No pollution report manipulation</th>
<th>Pollution report manipulation, but no reputation loss</th>
<th>Pollution report manipulation and reputation loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>(EU^P = b - \alpha - \beta b - ye - de)</td>
<td>(EU^P = b - \alpha - \beta b - \gamma(e - i) - de)</td>
<td>(EU^P = b - \alpha - \beta b - \gamma(e - i) - de - r i)</td>
<td></td>
</tr>
<tr>
<td>Individual optima: pollution level and manipulation level</td>
<td>(e^* = e_{\text{max}} - \frac{d}{c_e} = e_{\text{opt}})</td>
<td>(e^* = e_{\text{max}} - \frac{d}{c_e} + \frac{d}{c_e + c_i} + \frac{r}{c_i} (1 - \frac{1}{c_e + c_i}))</td>
<td>(e^* = e_{\text{max}} - \frac{d}{c_e} + \frac{d}{c_e - c_i} + \frac{r}{c_i} (c_e + c_i))</td>
</tr>
<tr>
<td></td>
<td>(i^* = \frac{d}{c_e + c_i})</td>
<td>(i^* = \frac{c_i d}{c_e + c_i} + \frac{r}{c_i} (c_e + c_i))</td>
<td>(i^* = \frac{c_i (c_e + c_i)}{c_e + c_i} + \frac{r}{c_i} (c_e - c_i))</td>
</tr>
<tr>
<td>Environmental compensation contract parameter</td>
<td>(\gamma = -d)</td>
<td>(\gamma = -\frac{c_i d}{c_e + c_i})</td>
<td>(\gamma = \frac{1}{c_e + c_i} (r c_e - d c_i))</td>
</tr>
<tr>
<td>Expected utility of shareholders in equilibrium</td>
<td>(\frac{1}{2} \frac{1}{c_b} - \frac{1}{2} \left( e_{\text{max}} - \frac{d}{2 c_e} \right))</td>
<td>(\frac{1}{2} \frac{1}{c_b} - \frac{1}{2} \left( e_{\text{max}} - \frac{1}{2 c_e} + \frac{i^*}{2} \right))</td>
<td>(\frac{1}{2} \frac{1}{c_b} - \frac{1}{2} \left( \frac{c_i d}{c_e - c_i} \right) - de^* - r i^*)</td>
</tr>
</tbody>
</table>

If the shareholders suffer from reputation losses, the manager will be less inclined to manipulate the EPI. There will be no report manipulation with sufficiently large reputation losses, i.e.:\textsuperscript{19}

\[
\frac{d}{c_e} \leq \frac{r}{c_i}
\]  \hspace{1cm} (22)

Assuming that (22) does not hold, the manipulation incentive is mitigated, but does not disappear. Consequently, \(\gamma\) remains negative, but its absolute value decreases compared to the situation without reputation loss. The shareholders anticipate the manager’s report manipulation. To

\textsuperscript{18} \(\frac{c_i d}{c_e + c_i} < d\) holds because of \(\frac{c_i}{c_e + c_i} < 1\).

\textsuperscript{19} Interestingly, this corner solution implies a maximum pollution level, \(e^* = e_{\text{max}}\). Only then is the manager able to truthfully state that there was no reporting manipulation. Consequently, no reputation loss will occur.
achieve lower manipulation levels, the shareholders allow some more units of pollution, because otherwise the manager’s incentive compatibility constraints would not be met and the manager would not sign the compensation contract. Consequently, the shareholders weaken the relationship between the manager’s remuneration and the EPI by reducing the absolute value of $\gamma$.

Reputation losses reduce the shareholders’ expected utility even more. Thus, under strict liability, the shareholders should be interested in using manipulation-proof environmental performance indicators. The measurement error, $\varepsilon$, remains not be relevant under strict liability.

**Pollution report manipulation under a negligence regime**

Under a negligence rule, only shareholders’ expected utility differs from the case of strict liability. The manager’s expected utility and the constraints of the optimization problem do not change.

TABLE 6 summarizes the results under a negligence regime for three different scenarios: (a) when there is no reporting manipulation, (b) when there is manipulation, and no reputation loss of shareholders due to manipulation, (c) when there is manipulation and a subsequent reputation loss of shareholders. First, we analyze the results without reputation loss. In order to keep the interpretation of results simple, we will assume in the following the cost parameters to be equal: $c_e = c_i = c$. This simplification does not affect qualitative results, but allows us to highlight the impact of the liability regime and of reputation losses.

Without reputation losses, in equilibrium reporting manipulation occurs ($i^\ast$ is greater than 0). As a result, real pollution increases. Those findings are qualitatively the same as for strict liability.

\[ EU^P \text{ with R.L.} < EU^P \text{ without R.L.} < EU^P \text{ without i} \]
<table>
<thead>
<tr>
<th>Shareholders’ objective function</th>
<th>No pollution report manipulation</th>
<th>Pollution report manipulation, but no reputation loss</th>
<th>Pollution report manipulation and reputation loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E\mu^P$ = $b - \alpha - \beta b - ye - de \left(1 - \frac{y_{opt} - e + \varepsilon}{2\varepsilon}\right)$</td>
<td>$E\mu^P = b - \alpha - \beta b - \gamma(e - i) - de \left(1 - \frac{y_{opt} - e + i + \varepsilon}{2\varepsilon}\right)$</td>
<td>$E\mu^P = b - \alpha - \beta b - ye + \gamma i - de \left(1 - \frac{y_{opt} - e + i + \varepsilon}{2\varepsilon}\right) - ri$</td>
<td></td>
</tr>
</tbody>
</table>

Individual optima: pollution level and manipulation level

- $e^* = e_{max} - \frac{d}{2c_e} - \frac{d e_{max} d}{2(\varepsilon c_e + d)}$
- $y^* = -\gamma \left(\frac{d}{2c_e} \frac{e_{max} d}{(\varepsilon c_e + d)}\right) = -\frac{d e_{max} c_e}{2d + \varepsilon c_e} - \frac{c_i d}{2(c_e + c_i)}$
- $i^* = \frac{d e_{max} c_e}{2c_i(d + \varepsilon c_e)} + \frac{d}{2(c_e + c_i)}$

Environmental compensation contract parameter

- $\gamma = -\frac{d e_{max} c_e}{2d + \varepsilon c_e} - \frac{c_i d}{2(c_e + c_i)}$
- $\gamma = -\frac{1}{2} c_i (e_{max} - e^*) - \frac{e_{max} - e^*}{2\varepsilon} - de^* \left(\frac{1}{2} - \frac{y_{opt} - e^* + \varepsilon c_e (e_{max} - e^*)}{2\varepsilon}\right)$

Expected utility of the shareholders in equilibrium

- $\frac{1}{2} c_i - \frac{1}{2} c_e (e_{max} - e^*)^2$
- $\frac{1}{2} c_i - \frac{1}{2} c_e (y_{opt} - e^*)^2 \left(1 + \frac{c_e}{c_i}\right)$
- $\frac{1}{2} c_i - \frac{1}{2} c_e (e_{max} - e^*)^2 \left(1 + \frac{c_e}{c_i}\right)$

What is different from strict liability is that the shareholders benefit from pollution report manipulation. It is important to keep in mind that, with a negligence regime, the shareholders only pay damage compensation when they are found negligent, which in turn depends on what the EPI reports. Since the EPI is the only verifiable measure of real pollution, manipulation of the EPI reduces the probability of being held liable. It is in this way that shareholders benefit from pollution report manipulation.

Less precise indicators, that is, higher values of $\varepsilon$, lead to less pollution report manipulation activity, $(\partial i^*/\partial \varepsilon) < 0$. The reason is that less precise measurement techniques reduce the marginal benefit of manipulation activities. As mentioned above, under strict liability, manipulation...
incentives were not tied to $\epsilon$. However, under a negligence rule, more precise measurement techniques imply higher marginal benefits for the manipulation activity. As a consequence, manipulation pays off for shareholders more the more precise the measurement technique is.

**RESULT 2:** When we allow for pollution report manipulation, the manager is inclined to manipulate reports, which in turn increases real pollution and future damages. Under strict liability, the company’s shareholders are fully responsible for damages, and thus they are worse off when reporting manipulation is possible. In contrast, under a negligence regime, the company’s shareholders benefit from reporting manipulation, since this reduces the likelihood of being held negligent and of damage compensation payments. This “benefit” becomes higher the more precise the measurement is.

Overall, we find a negative association between environmental performance and reporting manipulation, which is consistent with the empirical findings of, for example, Clarkson et al. (2008). Still, while the theoretical foundation in Clarkson et al. (2008) refers to an information argument, specifically self-selection effects, the main driver in our model is the liability regime and – in case of strict liability – an agency problem on top of it.

When we introduce a reputation loss, we obtain analogous results to the findings under strict liability: the level of reporting manipulation $i^*$ decreases while real pollution $e^*$ increases. Sufficiently high reputation losses eat up the shareholders’ benefit from manager’s manipulation. Because the shareholders anticipate possible future reputation loss as a result of pollution report manipulation, the contract design will induce the manager to reduce manipulation. But this im-
plies higher real pollution levels in equilibrium in order to meet the manager’s incentive compatibility constraints. Further analysis shows that punitive damages are suitable to induce the manager both to prevent pollution report manipulation and to reduce real pollution.21

5. Conclusion

This paper analyzes a manager’s incentives for the precise measurement and fair disclosure of environmental pollution levels, given that this information can be used to make shareholders liable for environmental damages. Real pollution levels are assumed not to be verifiable, but reported pollution levels are. We allow for three liability regimes: no liability, strict liability and a negligence rule. With strict liability, the company is held liable whenever pollution causes damages. With a negligence regime, the company is held liable if pollution causes damages and, additionally, if the company acted negligently, that is, failed to meet the standard of due care specified by legal rules. To the best of our knowledge, this is the first paper highlighting the interaction between the environmental liability regime and pollution reporting incentives.

If there is no reporting manipulation, we find that a strict liability rule tends to provide efficient incentives to reduce pollution. However, a strict liability rule does not induce the manager to measure pollution as precisely as possible. With a negligence regime, however, it is important to know whether the company’s pollution exceeds the standard level allowed by law or not. With more precision on pollution measurement, it is less likely that the measurement device reports non-tolerable pollution levels even though real pollution is lower and does not indicate negligence. Due to this Type I error, real pollution is generally lower than the socially optimal pollution level.

21 This analysis is available on request from the authors.
When we allow for pollution report manipulation, the manager is inclined to manipulate reports, which in turn impairs the need to reduce real pollution. Thus, pollution increases and so do damages. Under strict liability, the company’s shareholders are fully responsible for damages, and thus they are worse off when reporting manipulation is possible. In contrast, under a negligence regime, the company’s shareholders benefit from reporting manipulation, since this reduces the likelihood of negligence and damage compensation. This “benefit” is higher the more precise the measurement is.

Therefore, overall, we find that, while a negligence regime better encourages more precise pollution measurement than strict liability, it also provides stronger incentives for manipulation. We find complex results on the association between environmental performance and environmental disclosure, which may help to explain the mixed empirical evidence. When disclosure is characterized by measurement precision, this association is non-monotonic; when it is reflected by the absence of reporting manipulation, this association is positive.

Regulatory bodies may still be able to capture the benefit of a negligence rule while mitigating its negative effect on reporting manipulation if the financial and/or product markets sufficiently penalize the company with reputation losses. For this reason, regulatory bodies might want to set up a public register for companies that have been proven to manipulate reported pollution levels.

There are also limitations to mention. We do not thoroughly analyze the impact of the manager’s personal liability and do not explicitly allow for the manager’s capacity constraints. Basic analyses suggest, however, that the qualitative results may not change too much. Moreover, we assume that victims do not bear transaction costs when bringing lawsuits, while in fact these costs are positive. This would add a third player and would require a game-theoretical extension.
References

**Literature**


*Directives and regulations*


Online resources


Appendix

A1: Results under no liability

TABLE A1: Results without liability

<table>
<thead>
<tr>
<th>Lagrange multipliers</th>
<th>$\lambda = 1$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\mu = 0$</td>
</tr>
<tr>
<td></td>
<td>$\nu = 0$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Manager’s actions</th>
<th>$b^* = \frac{1}{c_b}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$e^* = e_{max}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Compensation contract parameter</th>
<th>$\alpha = -\frac{1}{2} \cdot \frac{1}{c_b}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\beta = 1$</td>
</tr>
<tr>
<td></td>
<td>$\gamma = 0$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Expected utility</th>
<th>$EU^P = b^* - \alpha = \frac{1}{2} \cdot \frac{1}{c_b}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$EU^M = 0$</td>
</tr>
</tbody>
</table>

First, it can be observed that IC 1 and IC 2 are not binding, because the Lagrange multipliers become zero. This is not surprising, because without the risk aversion of one player, the first-best contract can be achieved. The manager’s actions cannot be observed directly by the shareholders, but without risk aversion, the shareholders can implement a forcing contract. The manager is always pushed to her zero reservation utility by the fixed salary part $\alpha$, such that any deviation from her optimal actions $b^*$ and $e^*$, expressed by IC 1 and IC 2, would not change her expected utility and the Lagrange multipliers become zero. Second, since the shareholders are assumed to bear no liability costs, pollution will reach the maximum level, $e_{max}$. The compensation contract has the form of $s(\bar{x}, \bar{y}) = -(1/2) \cdot (1/c_b) + 1 \cdot \bar{x} = s(\bar{x})$.

---

22 See, for example, Holmström (1979); Feltham and Xie (1994) or Segerson and Tietenberg (1992).
A2: Socially optimal pollution levels

The expected social cost of pollution reads as:

\[
EC(e) = \frac{1}{2} c_e (e_{\text{max}} - e)^2 + \frac{e}{e_{\text{max}}} D
\]  

(A 1)

The first partial derivative is:

\[
\frac{\partial EC}{\partial e} = 0 = -c_e (e_{\text{max}} - e) + \frac{1}{e_{\text{max}}} D
\]

(A 2)

Proof of the sufficient condition is:

\[
\frac{\partial EC^2}{\partial^2 e} = c_e > 0 \text{ per definitionem}
\]

(A 3)

Rearranging the first partial derivative:

\[
e_{\text{opt}} = e_{\text{max}} - D \frac{1}{c_e} e_{\text{max}} - \frac{d}{c_e}
\]

(A 4)

A3: Results under strict liability

The shareholders’ objective function under strict liability is:

\[
\max_{\alpha, \beta, \gamma, b, e} EU^P = b - \alpha - \beta b - \gamma e - \frac{e}{e_{\text{max}}} D
\]

(A 5a)

The resulting Lagrange function is reflected by:

\[
L = b - \alpha - \beta b - \gamma e - \frac{e}{e_{\text{max}}} D
\]

\[
+ \lambda \left( \alpha + \beta b + \gamma e - \frac{1}{2} c_b b^2 - \frac{1}{2} c_e (e_{\text{max}} - e)^2 - U \right)
\]

\[
+ \mu (\beta - c_b b) + u (\gamma + c_e (e_{\text{max}} - e))
\]

(A 5b)

Optimization yields the results summarized in TABLE A2. Again, IC 1 and IC 2 are not binding, because the particular Lagrange multipliers become zero. Moreover, the manager’s effort for
“business as usual” does not change, because the liability payments only depend on the pollution level. The manager chooses the socially optimal pollution level \( e_{opt} \) derived in 2.3.

**TABLE A2: Results under strict liability**

<table>
<thead>
<tr>
<th>Lagrange multipliers</th>
<th>( \lambda = 1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \mu = 0 )</td>
<td></td>
</tr>
<tr>
<td>( \nu = 0 )</td>
<td></td>
</tr>
</tbody>
</table>

**Manager’s actions**

\[
\begin{align*}
    b^* &= \frac{1}{c_b} \\
    e^* &= e_{max} - \frac{d}{c_e} = e_{opt}
\end{align*}
\]

**Compensation contract parameter**

\[
\begin{align*}
    \alpha &= -\frac{1}{2} \cdot \frac{1}{c_b} + d \left( e_{max} - \frac{1}{2} \cdot \frac{d}{c_e} \right) \\
    \beta &= 1 \\
    \gamma &= -d
\end{align*}
\]

**Expected utility**

\[
\begin{align*}
    EU^P &= b^* - \alpha = \frac{1}{2} \cdot \frac{1}{c_b} - d \left( e_{max} - \frac{1}{2} \cdot \frac{d}{c_e} \right) \\
    EU^M &= 0
\end{align*}
\]

The compensation contract is \( s(\tilde{x}, \tilde{y}) = -(1/2) \cdot (1/c_b) + d(e_{max} - (1/2) \cdot (d/c_e)) + 1 \cdot \tilde{x} - d \cdot \tilde{y} \). With higher absolute values of \( \tilde{y} \), the manager receives less compensation. Because \( e_{max} - (1/2) \cdot (d/c_e) > 0 \) holds, the fixed part of the salary, \( \alpha \), increases in comparison to the no liability case. The amount of the fixed salary increases in order to compensate for the manager’s disutility resulting from decreasing pollution levels. The increase in fixed salary decreases the shareholders’ expected utility implying higher agency cost.

**A4: Results under negligence given that liability is possible, \( P(\tilde{y} \leq y_{opt}) < 1 \)**

The expected utility of the shareholders reads:
\[ EU_{negl}^p = b - \alpha - \beta b - \gamma e - \frac{e}{e_{\text{max}}}D \cdot P(\tilde{y} > y_{\text{opt}}) \]
\[ = b - \alpha - \beta b - \gamma e - \frac{e}{e_{\text{max}}}D \cdot \left(1 - \frac{y_{\text{opt}} - e + \varepsilon}{2\varepsilon}\right) \quad (A\ 6a) \]

In analogy to the case of strict liability and no liability, the Lagrange function follows as:

\[ L = b - \alpha - \beta b - \gamma e - \frac{e}{e_{\text{max}}}D \cdot \left(1 - \frac{y_{\text{opt}} - e + \varepsilon}{2\varepsilon}\right) \]
\[ + \lambda \left(\alpha + \beta b + \gamma e - \frac{1}{2} c_b b^2 - \frac{1}{2} c_e(e_{\text{max}} - e)^2 - U\right) \]
\[ + \mu(\beta - c_b b) + \nu(\gamma + c_e(e_{\text{max}} - e)) \quad (A\ 6b) \]

The results of the Lagrange optimization are summarized in TABLE A3.

**TABLE A3: Results under negligence (when liability is possible: \( P(\tilde{y} \leq y_{\text{opt}}) < 1 \))**

<table>
<thead>
<tr>
<th>Lagrange multipliers</th>
<th>( \lambda = 1 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \mu = 0 )</td>
<td></td>
</tr>
<tr>
<td>( \nu = 0 )</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Manager’s actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>( b^* = \frac{1}{c_b} )</td>
</tr>
<tr>
<td>( e^* = e_{\text{max}} - \frac{d}{2c_e} - \frac{e_{\text{max}}d}{2(\varepsilon c_e + d)} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Compensation contract parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha = -\frac{1}{2} \cdot \frac{1}{c_b} + \frac{c_e}{2} \left(e_{\text{max}}^2 - e^{*2}\right) )</td>
</tr>
<tr>
<td>( \beta = 1 )</td>
</tr>
<tr>
<td>( \gamma = c_e(e^* - e_{\text{max}}) = -c_e \left(\frac{d}{2c_e} + \frac{e_{\text{max}}d}{2(\varepsilon c_e + d)}\right) )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Expected utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>( EU^p = \frac{1}{2} \cdot \frac{1}{c_b} - \frac{c_e}{2} \left(e_{\text{max}}^2 - e^{<em>2}\right) - de^</em> \left(\frac{1}{2} - \frac{y_{\text{opt}} - e^*}{2\varepsilon}\right) )</td>
</tr>
<tr>
<td>( EU^M = 0 )</td>
</tr>
</tbody>
</table>

Again, IC 1 and IC 2 are not binding, just as in the case of strict liability and no liability. The compensation contract has the form of \( s(\tilde{x}, \tilde{y}) = -(1/2) \cdot (1/c_b) + (c_e/2)(e_{\text{max}}^2 - e^{*2}) + 1 \cdot \tilde{x} + c_e(e^* - e_{\text{max}}) \cdot \tilde{y} \). The optimal contract depends on the company’s pollution level \( e^* \) in equilibrium. The parameter \( \gamma \) is again negative, because \( c_e(e^* - e_{\text{max}}) < 0 \). The link between the manager’s compensation and the EPI – as reflected by \( \gamma \) – becomes stronger the more precise the EPI gets. Moreover, the following relations hold:
\[ e^* \leq y_{opt} \quad (A\ 6c) \]
\[ e^* \geq 0 \quad (A\ 6d) \]
\[ \frac{\partial e^*}{\partial \varepsilon} > 0 \quad \text{if} \ e_{max}, c_e > 0 \quad (A\ 6e) \]

**Proof of (A 6c) \( e^* \leq y_{opt} \)**

The company’s pollution level in equilibrium is defined by:

\[ e^* = \frac{\varepsilon c_e e_{max} + \frac{d}{2}(y_{opt} - \varepsilon)}{\varepsilon c_e + d} \quad (A\ 7a) \]

If \( e^* \leq y_{opt} \) is valid:

\[ e^* \leq y_{opt} \leftrightarrow e^* - y_{opt} \leq 0 \quad (A\ 7b) \]

By inserting \( e^* \) and multiplying by \( \varepsilon c_e + d \):

\[ \varepsilon c_e e_{max} + \frac{d}{2}(y_{opt} - \varepsilon) - y_{opt} \varepsilon c_e - d y_{opt} \leq 0 \quad (A\ 7c) \]

Rearranging:

\[ \varepsilon c_e (e_{max} - y_{opt}) - \frac{d}{2}(y_{opt} + \varepsilon) \leq 0 \quad (A\ 7d) \]

Inserting \( y_{opt} = e_{max} - \frac{d}{c_e} \):

\[ \varepsilon c_e \left(e_{max} - e_{max} + \frac{d}{c_e}\right) - \frac{d}{2}\left(e_{max} - \frac{d}{c_e} + \varepsilon\right) \leq 0 \quad (A\ 7e) \]

Rearranging:

\[ \varepsilon d - \frac{d}{2} e_{max} + \frac{d^2}{2c_e} - \frac{\varepsilon d}{2} \leq 0 \quad (A\ 7f) \]

Multiplying by \( 2/d \):

\[ 2\varepsilon - e_{max} + \frac{d}{c_e} - \varepsilon \leq 0 \quad (A\ 7g) \]

Rearranging:

\[ \varepsilon \leq e_{max} - \frac{d}{c_e} = y_{opt} \quad (A\ 7h) \]

Since we assume \( \varepsilon \leq e_{opt} = y_{opt} \), also \( e^* \leq y_{opt} \) holds. \( \quad q.e.d. \)
Proof of (A 6d) $e^* \geq 0$

$$e^* = \frac{\varepsilon c_e e_{\text{max}} + \frac{d}{2}(y_{\text{opt}} - \varepsilon)}{\varepsilon c_e + d}$$ \hspace{1cm} (A 8a)

If $\varepsilon \leq y_{\text{opt}}$ is valid, all mathematical terms in (A 8a) will be positive per definitionem. As a consequence, $e^*$ must be positive as well.

$q.e.d.$

Proof of (A 6e) $\frac{\partial e^*}{\partial \varepsilon} > 0$

$$e^* = e_{\text{max}} - \frac{d}{2c_e} - \frac{e_{\text{max}} d}{2(\varepsilon c_e + d)}$$ \hspace{1cm} (A 9a)

The first partial derivative is:

$$\frac{\partial e^*}{\partial \varepsilon} = \frac{e_{\text{max}} d \cdot c_e}{2(\varepsilon c_e + d)^2} > 0 \text{ per definitionem}$$ \hspace{1cm} (A 9b)

$q.e.d.$

Derivative of the shareholders’ expected utility under negligence:

$$E U^P = \frac{1}{2} \cdot \frac{1}{c_b} - \frac{U}{2} - \frac{c_e}{2} (e_{\text{max}} - e^*)^2 - d e^* \left(\frac{1}{2} - \frac{y_{\text{opt}} - e^*}{2\varepsilon}\right)$$ \hspace{1cm} (A 10a)

The first partial derivative with respect to $\varepsilon$ is:

$$\frac{\partial E U^P}{\partial \varepsilon} = c_e (e_{\text{max}} - e^*) \cdot \frac{\partial e^*}{\partial \varepsilon} - \frac{d}{2} \cdot \frac{\partial e^*}{\partial \varepsilon} + d \frac{y_{\text{opt}} - e^*}{2\varepsilon} \cdot \frac{\partial e^*}{\partial \varepsilon}$$

$$+ d e^* \cdot \left(\frac{-\frac{\partial e^*}{\partial \varepsilon} \cdot 2\varepsilon - (y_{\text{opt}} - e^*) \cdot 2}{4\varepsilon^2}\right)$$ \hspace{1cm} (A 10b)

With:
\[
\frac{\partial e^*}{\partial \varepsilon} = \frac{e_{max} d \cdot e}{2(\varepsilon c_e + d)^2}
\]  

(A 10c)

By inserting (A 10c) and simplifying:

\[
\frac{\partial EU^p}{\partial \varepsilon} = -de^* \cdot \frac{y_{opt} - e^*}{2 \cdot e^2} \leq 0
\]  

(A 10d)

because \( y_{opt} \geq e^* \) is valid, (see Proof of (A 6c)) and \( d, e^*, y_{opt}, \varepsilon \geq 0 \).

A5: Results under negligence given that there is no liability, \( P(\bar{y} \leq y_{opt}) = 1 \)

Determination of the threshold measurement error \( \hat{\varepsilon} \) that ensures no liability. With no liability, it must hold:

\[
\frac{y_{opt} - \hat{\varepsilon}^* + \hat{\varepsilon}}{2\hat{\varepsilon}} = 1
\]  

(A 11a)

By inserting \( \hat{\varepsilon}^* = e_{max} - \frac{d}{2c_e} - \frac{e_{max} d}{2(\varepsilon c_e + d)} \) and rearranging:

\[
\hat{\varepsilon}^2 + \frac{3}{2} \frac{d}{c_e} \hat{\varepsilon} - \frac{1}{2} \frac{d}{c_e} y_{opt} = 0
\]  

(A 11b)

By using the approach for solving quadratic equations and rearranging:

\[
\hat{\varepsilon}_{1,2} = -\frac{3}{4} \frac{d}{c_e} \pm \frac{1}{4} \frac{d}{c_e} \sqrt{1 + \frac{8 c_e}{d} e_{max}}
\]  

(A 11c)

Whereas \( \hat{\varepsilon}_2 = -\frac{3}{4} \frac{d}{c_e} + \frac{1}{4} \frac{d}{c_e} \sqrt{1 + \frac{8 c_e}{d} e_{max}} \) drops because \( \hat{\varepsilon} \geq 0 \).

Check whether \( \hat{\varepsilon}_1 = -\frac{3}{4} \frac{d}{c_e} + \frac{1}{4} \frac{d}{c_e} \sqrt{1 + \frac{8 c_e}{d} e_{max}} \geq 0 \) is valid:
\[-\frac{3}{4} d + \frac{1}{4} d \sqrt{1 + \frac{c_e}{d} e_{\text{max}}} \geq 0\]

\[\frac{1}{4} d \left( -3 + \sqrt{1 + \frac{c_e}{d} e_{\text{max}}} \right) \geq 0\]

\[\sqrt{1 + \frac{c_e}{d} e_{\text{max}}} \geq 3\]

\[\frac{c_e}{d} e_{\text{max}} \geq 1\]

This is valid because of the assumption \(c_e e_{\text{max}} > d\).

q.e.d.

Shareholders’ expected utility \(E_{\text{U}}^P \) under the “no-liability-constraint” \(e^* + \varepsilon \leq y_{\text{opt}}\)

**TABLE A4:** Equilibrium pollution level \(e^*\) and shareholders’ expected utility with no liability under negligence and with liability under negligence

<table>
<thead>
<tr>
<th>(0 \leq \varepsilon \leq \hat{\varepsilon}: \text{no liability under negligence} )</th>
<th>(\varepsilon &gt; \hat{\varepsilon}: \text{liability possible} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>(e^* = y_{\text{opt}} - \varepsilon, \frac{\partial e^*}{\partial \varepsilon} = -1 &lt; 0 )</td>
<td>(e^* = e_{\text{max}} - \frac{d}{2c_e} - \frac{e_{\text{max}}d}{2(c_e+d)}, \frac{\partial e^*}{\partial \varepsilon} = \frac{e_{\text{max}}d c_e}{2(c_e+d)^2} &gt; 0 )</td>
</tr>
<tr>
<td>(E_{\text{U}}^P_{\text{not l.}} = \frac{1}{2} \cdot \frac{1}{c_b} - \frac{c_e}{2} \left( \frac{d}{c_e} + \varepsilon \right)^2 )</td>
<td>(E_{\text{U}}^P_{\text{negl}} = \frac{1}{2} \cdot \frac{1}{c_b} - \frac{c_e}{2} \left( \frac{d}{c_e} + \varepsilon \right)^2 - d e^* \left( \frac{1}{2} \cdot y_{\text{opt}} - e^* \right) )</td>
</tr>
<tr>
<td>(\frac{\partial E_{\text{U}}^P_{\text{not l.}}}{\partial \varepsilon} = -c_e \left( \frac{d}{c_e} + \varepsilon \right) &lt; 0 )</td>
<td>(\frac{\partial E_{\text{U}}^P_{\text{negl}}}{\partial \varepsilon} = -\frac{d \cdot e^<em>}{2 \varepsilon^2} \cdot (y_{\text{opt}} - e^</em>) &lt; 0 )</td>
</tr>
<tr>
<td>(E_{\text{U}}^P_{\text{not l. min}} = \frac{1}{2} \cdot \frac{1}{c_b} - U - \frac{1}{2} \frac{d^2}{c_e} - \frac{c_e \hat{\varepsilon}^2}{2} \text{ for } \varepsilon = y_{\text{opt}} )</td>
<td>(E_{\text{U}}^P_{\text{negl. min}} = \frac{1}{2} \cdot \frac{1}{c_b} - U - \frac{d e_{\text{max}}}{2} \text{ for } \varepsilon = y_{\text{opt}} )</td>
</tr>
<tr>
<td>(\varepsilon = \hat{\varepsilon} \text{ and } e^* = \hat{e}^* )</td>
<td>and (e^* = y_{\text{opt}} )</td>
</tr>
<tr>
<td>(E_{\text{U}}^P_{\text{not l. max}} = \frac{1}{2} \cdot \frac{1}{c_b} - U - \frac{1}{2} \frac{d^2}{c_e} \text{ for } \varepsilon = 0 )</td>
<td>(E_{\text{U}}^P_{\text{negl. max}} = \frac{1}{2} \cdot \frac{1}{c_b} - U - \frac{1}{2} \frac{d^2}{c_e} - \frac{c_e \hat{\varepsilon}^2}{2} \text{ for } \varepsilon = )</td>
</tr>
<tr>
<td>and (e^* = y_{\text{opt}} )</td>
<td>(\hat{\varepsilon} \text{ and } e^* = \hat{e}^* )</td>
</tr>
</tbody>
</table>
Since the manager receives a reservation utility of zero and there are no damage payments, the shareholders receive the financial income minus the manager’s disutility for her working effort regarding core business operations and the pollution-reducing task. This leads to shareholder’s expected utility of:

\[ EU_{\text{not } l.} \alpha = \frac{1}{2} \cdot \frac{1}{c_b} - \frac{c_e}{2} (e_{max} - e^*)^2 = \frac{1}{2} \cdot \frac{1}{c_b} - \frac{c_e}{2} \left( \frac{d}{c_e} + \varepsilon \right)^2 \] (A 12)

TABLE A4 summarizes the results with regard to the equilibrium pollution level \( e^* \) and with regard to the shareholders’ expected utility for the case in which the shareholders would not be found negligent and the case where liability is possible.

**A6: Pollution report manipulation under strict liability**

The manager’s pollution report manipulation influences the utility function of the manager through the additional disutility of the corresponding working effort:

\[ EU^M = \alpha + \beta b + \gamma (e - i) - \frac{1}{2} c_b b^2 - \frac{1}{2} c_e (e_{max} - e)^2 - \frac{1}{2} c_i i^2 \geq U = 0 \] (A 13a)

The individual rationality constraint (IR) follows directly from equation (A 13a). The incentive compatibility constraints (IC 1 and IC 2) must be complemented by one more equation for action \( i \) (IC 3):

\[
\frac{\partial EU^M}{\partial b} = 0 = \beta - c_b b^* \quad (A 13b)
\]

\[
\frac{\partial EU^M}{\partial e} = 0 = \gamma + c_e (e_{max} - e^*) \quad (A 13c)
\]

\[
\frac{\partial EU^M}{\partial i} = 0 = -\gamma - c_i i^* \quad (A 13d)
\]

Summarizing these relations into a Lagrange function by introducing the additional Lagrange multiplier \( \varphi \) for IC 3 yields:
\[ L = b - \alpha - \beta b - \gamma e + \gamma i - de + \lambda \left( \alpha + \beta b + \gamma e - \gamma i - \frac{1}{2} cb^2 - \frac{1}{2} ce(e_{\text{max}} - e)^2 - \frac{1}{2} ci^2 - U \right) + \mu (\beta - cb) + v (\gamma + ce(e_{\text{max}} - e)) + \phi (-\gamma - ci) \]

Optimization leads to the results in TABLE A5.

**TABLE A5 : Results under strict liability and pollution report manipulation**

<table>
<thead>
<tr>
<th></th>
<th>No reputation loss</th>
<th>Reputation loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lagrange multipliers</td>
<td>( \lambda = 1 )</td>
<td>( \lambda = 1 )</td>
</tr>
<tr>
<td></td>
<td>( \mu = 0 )</td>
<td>( \mu = 0 )</td>
</tr>
<tr>
<td></td>
<td>( v = \varphi = -i^* )</td>
<td>( v = \varphi = -i^* - \frac{r}{ci} )</td>
</tr>
<tr>
<td>Manager’s actions</td>
<td>( b^* = \frac{1}{cb} )</td>
<td>( b^* = \frac{1}{cb} )</td>
</tr>
<tr>
<td></td>
<td>( e^* = e_{\text{max}} - \frac{d}{ce + ci} )</td>
<td>( e^* = e_{\text{max}} + \left( \frac{d}{ce + ci} \right) \left( \frac{ce}{ce + ci} - 1 \right) )</td>
</tr>
<tr>
<td></td>
<td>( i^* = \frac{d}{ce + ci} )</td>
<td>( i^* = \frac{d}{ce + ci} )</td>
</tr>
<tr>
<td>Compensation contract parameter</td>
<td>( \alpha = U - \frac{1}{2} \frac{1}{cb} - \frac{1}{2} \frac{d^2}{ce} + \frac{d}{ce + ci} (c_i y_{\text{opt}} - \frac{d}{2}) )</td>
<td>( \alpha = U - \frac{1}{2} \frac{1}{cb} - \frac{1}{2} \frac{d^2}{ce} + \frac{d}{ce + ci} \left( c_i y_{\text{opt}} - \frac{d}{2} \right) )</td>
</tr>
<tr>
<td></td>
<td>( \beta = 1 )</td>
<td>( \beta = 1 )</td>
</tr>
<tr>
<td></td>
<td>( \gamma = - \frac{c_i d}{ce + ci} )</td>
<td>( \gamma = \frac{1}{ce + ci} (rc_e - dc_i) )</td>
</tr>
<tr>
<td>Expected utility</td>
<td>( EU^P = \frac{1}{2} \frac{1}{cb} - U - \frac{d}{2} \left( e_{\text{max}} - \frac{1}{2} \frac{d}{ce} \right) - \frac{d}{2} i^* )</td>
<td>( EU^P = \frac{1}{2} \frac{1}{cb} - U - \frac{c_i d}{2} i^* \left( \frac{d}{ce} - \frac{r}{ci} \right) - d e^* - ri^* )</td>
</tr>
<tr>
<td></td>
<td>( EU^M = U )</td>
<td>( EU^M = U )</td>
</tr>
</tbody>
</table>

IC 2 and IC 3 now become binding because of the exchange relationship between \( e \) and \( i \).\(^{23}\) The business-as-usual task is not influenced, so that \( b^* \) and \( \beta \) remain. In comparison to the initial strict liability model, the resulting pollution level is increased by exactly this manipulation level. Thus, the expected value of the EPI \( \tilde{y} \) remains at the optimal level \( y_{\text{opt}} \). The shareholders anticipate that the manager manipulated and so they reduces the proportion of the manipulated salary

\(^{23}\) Deviation from the optimal solutions in in TABLE A5 influence the expected utilities because \( i \) is not contractible.
part $\gamma$. As a consequence, the fixed salary parameter $\alpha$ can be reduced too: because the punishment for high values of $\tilde{y}$ is now lower than before, the shareholders can reduce $\alpha$ and still push the manager’s expected utility to the reservation wage. The range of the EPI, $\varepsilon$, is again neither important for the shareholders nor the manager, just as in the previous analysis of strict liability.

If it is possible to detect manipulation, the reputation loss will affect the expected utility function of the shareholders, and the Lagrange function will be:

$$L = b - \alpha - \beta b - \gamma e + \gamma i - de - ri$$
$$+ \lambda \left( \alpha + \beta b + \gamma e - \gamma i - \frac{1}{2} c_b b^2 - \frac{1}{2} c_e (e_{\text{max}} - e)^2 - \frac{1}{2} c_i i^2 - U \right) \quad (A\ 13f)$$
$$+ \mu (\beta - c_b b) + \nu (\gamma + c_e (e_{\text{max}} - e)) + \varphi (-\gamma - c_i i)$$

The results of this optimization problem are already included in TABLE A5. The introduction of a reputation loss reduces the level of pollution report manipulation in equilibrium $i^*$, because the cost parameters and $r$ are positive. Looking closely at $i^*$ and $e^*$ reveals the additional necessary assumption that $d/c_e > r/c_i$. Then, $\gamma$ remains negative, but its absolute value decreases compared to the situation without reputation loss. To reduce the level of pollution report manipulation, the shareholders accept more pollution. As a consequence, they weaken the relationship between the manager’s compensation and the pollution level by reducing the absolute value of $\gamma$. Therefore, they can also reduce the value of the fixed parameter $\alpha$. The expected utility of the manager is still pushed to her reservation wage. As one could expect, the introduction of reputation loss into our model lowers the expected utility of the shareholders even more.\textsuperscript{25}

\textsuperscript{24} Again, this fits with the general results from agency theory: linking compensation to performance measures becomes more effective the “better” (seemingly also “non-manipulable”) the performance measures are (e.g. Holmström and Milgrom (1991); Gabel and Sinclair-Desgagné (1993); Lothe and Myrtveit (2003)).

\textsuperscript{25} $EU^P_{\text{with R.L.}} < EU^P_{\text{without R.L.}} < EU^P_{\text{without i}}$
A7: Pollution report manipulation under negligence

Under negligence, the definition of pollution report manipulation \( i \) as well as the expected utility of the manager do not change. The constraints of the optimization problem are the same as before. Only the shareholders’ expected utility is affected, so the Lagrange function follows as:

\[
L = b - \alpha - \beta b + \gamma e + \gamma i - de \left( 1 - \frac{y_{opt} - e + i + \varepsilon}{2\varepsilon} \right) + \lambda \left( \alpha + \beta b + \gamma e - \gamma i - \frac{1}{2} c_b b^2 - \frac{1}{2} c_e e_{max} - e - \frac{1}{2} c_i i^2 - U \right) + \mu (\beta - c_b b) + \nu (\gamma + c_e e_{max} - e) + \varphi (-\gamma - c_i i)
\]

\[ (A \ 14a) \]

| TABLE A6: Results under negligence and pollution report manipulation |
|---------------------------------|-----------------|
| **Lagrange multipliers**       | No reputation loss | Reputation loss |
| \( \lambda = 1 \)             | \( \lambda = 1 \) |
| \( \mu = 0 \)                  | \( \mu = 0 \)     |
| \( v = \varphi = \frac{de^*}{2\varepsilon c_i} - i^* \) | \( v = \varphi = -i^* - \frac{r}{c_i} + \frac{de^*}{2\varepsilon c_i} \) |

<table>
<thead>
<tr>
<th>Manager’s actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>( b^* = \frac{1}{c_b} )</td>
</tr>
<tr>
<td>( e^* = e_{max} - \frac{d e_{max}}{dc_i} )</td>
</tr>
<tr>
<td>( i^* = \frac{d e_{max} e_i}{2c_i (d + \varepsilon e)} + \frac{d}{2 (c_e + c_i)} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Compensation contract parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha = U - \frac{1}{2} \frac{1}{c_b} + \frac{1}{2} c_e (e_{max} - e^*) \left( \frac{1 + \frac{c_e}{c_i}}{c_i} \right) )</td>
</tr>
<tr>
<td>( + c_e (e_{max} - e^<em>) \left( \frac{e^</em> - \frac{c_e}{c_i} (e_{max} - e^*)}{c_i} \right) )</td>
</tr>
<tr>
<td>( \beta = 1 )</td>
</tr>
<tr>
<td>( \gamma = - \frac{d e_{max} c_e}{2 (d + \varepsilon c_e)} - \frac{c_i d}{2 (c_e + c_i)} + \frac{\varepsilon c_e^2}{(d + \varepsilon c_e) (c_e + c_i)} )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Expected utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>( EU^P )</td>
</tr>
<tr>
<td>( = \frac{1}{2} \frac{1}{c_b} - U - \frac{1}{2} c_e (e_{max} - e^*) \left( \frac{1 + \frac{c_e}{c_i}}{c_i} \right) )</td>
</tr>
<tr>
<td>( - \frac{de^<em>}{2 \varepsilon} \left( \frac{y_{opt} - e^</em> + \frac{c_e}{c_i} (e_{max} - e^*)}{2\varepsilon} \right) )</td>
</tr>
<tr>
<td>( EU^M = U )</td>
</tr>
<tr>
<td>( EU^P )</td>
</tr>
<tr>
<td>( = \frac{1}{2} \frac{1}{c_b} - U - \frac{1}{2} c_e (e_{max} - e^*) \left( \frac{1 + \frac{c_e}{c_i}}{c_i} \right) )</td>
</tr>
<tr>
<td>( - \frac{de^<em>}{2 \varepsilon} \left( \frac{y_{opt} - e^</em> + \frac{c_e}{c_i} (e_{max} - e^*)}{2\varepsilon} \right) )</td>
</tr>
<tr>
<td>( - \frac{r \ c_e}{c_i} (e_{max} - e^*) )</td>
</tr>
<tr>
<td>( EU^M = U )</td>
</tr>
</tbody>
</table>
TABLE A6 summarizes the results of this optimization problem. The Lagrange multipliers reveal no surprising results. Only the absolute value of $\nu$ and $\varphi$ have changed. $b^*$ and $\beta$ have not change either, which is comprehensible. In accordance with the results under strict liability, the pollution level in equilibrium $e^*$ increases, and the pollution report manipulation in equilibrium $i^*$ is greater than zero. Both activity levels in equilibrium depend on the range of the EPI, $\varepsilon$. Compared to the situation without pollution report manipulation, $\gamma$ decreases\(^{26}\) so that again the linkage between the EPI $\bar{y}$ and the manager’s compensation is weakened, just as it was observed under strict liability. Here again, the shareholders lower the fixed salary part $\alpha$ because they do not need to compensate for the manager’s punishment for pollution that much. As always in this setting, the manager is pushed to her reservation wage.

The difference between the shareholders’ expected utility with pollution report manipulation and without is:

$$\Delta EU^P = \frac{d^2(c_e^2(2e_{max}^2 - \varepsilon^2) - d^2 - 2c_e d\varepsilon)}{16c_e^2\varepsilon(d + c_e\varepsilon)} > 0$$ (A 15a)

which holds for $d, c_e > 0$ and for every $\varepsilon$ where $0 \leq \varepsilon \leq e_{max} - \frac{d}{c_e} = e_{opt}$. Because

$$\frac{\partial \Delta EU^P}{\partial \varepsilon} < 0$$ (A 15b)

the difference between the shareholders’ expected utility increases as the measurement technique becomes more precise. Therefore, shareholders increasingly benefit from report manipulation the more precise the measurement technique is.

**Results under negligence, with reputation loss**

The Lagrange function equals:

\(^{26}\) because $\frac{c_i}{c_e + c_i} < 1$
\[ L = b - \alpha - \beta b - ye + yi - de \left( 1 - \frac{y_{opt} - e + i + \varepsilon}{2\varepsilon} \right) - ri \]
\[ + \lambda \left( \alpha + \beta b + ye - yi - \frac{1}{2} c_b b^2 - \frac{1}{2} c_e (e_{max} - e)^2 - \frac{1}{2} c_i i^2 - U \right) \]
\[ + \mu (\beta - c_b b) + v (y + c_e (e_{max} - e)) + \varphi (-\gamma - c_i i) \]  

(A 16a)

The results of this optimization problem are included in TABLE A6. As one would expect, the Lagrange multipliers as well as the business–as-usual activity in equilibrium \( b^* \) and the corresponding compensation parameter \( \beta \) remain unaffected. To ensure positive values of the manager’s pollution report manipulation activity in equilibrium, once again one condition must be fulfilled:

\[ \frac{r}{c_i} < \frac{d}{c_e} \left( \frac{e_{max} + e_{max} c_e + \varepsilon + \frac{d}{c_e}}{2\varepsilon} \right) \]  

(A 16b)

This is always the case, because for \( \varepsilon \leq y_{opt} = e_{max} - (d/c_e) \), the expression in brackets is greater than 1. Thus, if the assumption of \( r/c_i < d/c_e \) holds, equation (A 16b) is always fulfilled. The introduction of reputation loss in this model does not change the fact that more precise environmental indicators induce lower pollution levels \( e^* \) but higher pollution report manipulation levels \( i^* \) in equilibrium.\(^{27}\) Again, in correspondence with the results under strict liability, the absolute value of \( \gamma \) is reduced, and thereby also the value of the fixed salary parameter \( \alpha \). The manager’s expected utility is pushed to her reservation utility. Given that the expected reputation loss is not so crucial that any pollution report manipulation is deterred, i.e. \( r/c_i < d/c_e \), the difference between the shareholders’ expected utility with pollution report manipulation and reputation loss and her expected utility with pollution report manipulation but without reputation loss is always negative. This means that, in a situation when the manager can manipulate the

\(^{27}\) because \( \frac{\partial e^*}{\partial \varepsilon} > 0 \) and \( \frac{\partial i^*}{\partial \varepsilon} < 0 \)
pollution report, the company does not want the public to become aware of this. This result seems to be intuitive.

Moreover, for sufficiently high reputation losses, i.e. \( r \geq \hat{r} \), the difference between the shareholders’ expected utility with pollution report manipulation and reputation loss on the one hand, and their expected utility in the initial negligence model on the other hand, turns negative. This \( \hat{r} \) is derived from equating the shareholders’ expected utility in the initial negligence model and in the situation with report manipulation:

\[
E_U^{P\text{ with R.L.}} = E_U^{P\text{ without i}}
\]

\[
\hat{r}_{1,2} = \frac{d^2}{ce} + 2de_{\max} + d\epsilon - \frac{\sqrt{\sqrt{d^4 + 2c_e d^3 e_{\max} + c_e^2 d^2 e_{\max}^2 + 2c_e d^3 \epsilon + 2c_e^2 d^2 \epsilon e_{\max} + c_e^2 d^2 \epsilon^2}}}{2\epsilon}
\]

Because \( r/c_i \leq d/c_e \), \( \hat{r} \) is clearly defined by:

\[
\hat{r} = \frac{d^2}{ce} + 2de_{\max} + d\epsilon - \frac{\sqrt{\sqrt{d^4 + 2c_e d^3 e_{\max} + c_e^2 d^2 e_{\max}^2 + 2c_e d^3 \epsilon + 2c_e^2 d^2 \epsilon e_{\max} + c_e^2 d^2 \epsilon^2}}}{2\epsilon}
\]

for \( c_e > 0, 0 < \epsilon < e_{\max} - (d/c_e) = e_{opt}, r/c_i < d/c_e \) and \((1/2)c_e e_{\max}^2 > D \) or \( e_{\max} \geq d/c_e \) respectively. Note that this particular \( \hat{r} \) depends on the measurement precision \( \epsilon \). As a result, if there were a chance that the public could punish the company for manipulated pollution reports through sufficiently high reputation loss, e.g. if there is an adequate verification process and a public register for companies that have been proven to report manipulated pollution levels, the company would be better off with a system where the manipulation of pollution reports is impossible \textit{per se}. 

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**A8: Linear capacity constraint**

Introducing a linear capacity constraint, $\kappa$, which limits the manager’s maximum working effort that can be allocated to the two tasks, results in the addition of the following constraint to the optimization problem:

$$e_{\text{max}} - e + b \leq \kappa \quad (A\ 17a)$$

Adding this constraint to the Lagrange function (A 5b) or (A 6b) through the Lagrange multiplier $\phi$ leads indeed to a reaction function regarding the tasks $b$ and $e$.

In principle, all pairs of $(b, e)$ that satisfy these reaction functions are possible results of how the manager could split her maximum working effort. However, by defining the parameters of the compensation contract $\alpha, \beta, \gamma$, the shareholders can influence the manager about which of these possible pairs she has to choose. The case of sufficient capacity is trivial, because the shareholders would induce her toward expected utility maximizing efforts $(b^*, e^*)$. Inserting the results from Table A7, lines (1) and (2), into the shareholders’ expected utility function (11) or (15) and subsequently maximizing the function leads to this insight in a mathematical way.

A binding capacity constraint leads to individually optimal working efforts that depend on the maximum available working effort $\kappa$ in accordance with lines (3) and (4) of Table A8. As lines (5) and (6) show, the relation of the cost parameters $c_e$ and $c_b$ determine which task will be preferred if the maximum available capacity changes under strict liability. For example, if $c_e < c_b$ and the maximum available capacity is reduced, the manager will shift her effort to the pollution-reducing action, because this task is cheaper for her; the reverse is also true. Under negligence, both actions will be reduced or expanded simultaneously if the maximum available capacity, $\kappa$, is reduced or expanded. The reduction of pollution in this case lowers the probability of becoming liable and thereby creates more utility for the shareholders. Thus, in equilibrium the manager will not reduce the working effort for one task unilaterally if $\kappa$ is reduced, but she will reduce the effort for both tasks simultaneously.
TABLE A7: Results under introducing a linear capacity constraint

<table>
<thead>
<tr>
<th></th>
<th>Strict liability</th>
<th>Negligence</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Reaction function</td>
<td>[ b(e) = \frac{c_b(e - e_{\text{max}}) + d + 1}{c_b} ]</td>
<td>[ b(e) = \frac{c_b(e_{\text{max}} - e)}{c_b} - \frac{d}{c_b} \left( \frac{1}{2} - \frac{y_{\text{opt}} - e}{\epsilon} \right) + \frac{1}{c_b} ]</td>
</tr>
<tr>
<td>(2) First derivative of the reaction function</td>
<td>[ \frac{\partial b}{\partial e} = \frac{c_e}{c_b} ]</td>
<td>[ \frac{\partial b}{\partial e} = -\frac{e}{c_b} - \frac{1}{\epsilon} ]</td>
</tr>
<tr>
<td>(3) b’s reaction to ( \kappa ) (binding linear capacity constraint)</td>
<td>[ b(\kappa) = -\frac{c_b \kappa - d - 1}{c_b - c_e} ]</td>
<td>[ b(\kappa) = \frac{2(c_b \kappa + e) + d(2c_e - 2c_{\text{max}} + e(y_{\text{opt}} - 1))}{2(c_b + c_e) + d} ]</td>
</tr>
<tr>
<td></td>
<td>[ \frac{\partial b}{\partial \kappa} = -\frac{c_e}{c_b - c_e} ]</td>
<td>[ \frac{\partial b}{\partial \kappa} = \frac{c_e + d}{(c_b + c_e) + d} ]</td>
</tr>
<tr>
<td>(4) e’s reaction to ( \kappa ) (binding linear capacity constraint)</td>
<td>[ e(\kappa) = c_{\text{max}} - \frac{-c_b \kappa + d + 1}{c_e - c_b} ]</td>
<td>[ e(\kappa) = \frac{e(-2c_b \kappa + c_b e_{\text{max}} + 2c_e e_{\text{max}} - d + 2) + dy_{\text{opt}}}{2(c_e + c_b) + d} ]</td>
</tr>
<tr>
<td></td>
<td>[ \frac{\partial e}{\partial \kappa} = \frac{c_b}{c_e - c_b} ]</td>
<td>[ \frac{\partial e}{\partial \kappa} = \frac{-c_b e}{e(c_b + c_e) + d} ]</td>
</tr>
<tr>
<td>(5) ( c_e &lt; c_b ) (binding linear capacity constraint)</td>
<td>[ \frac{\partial b}{\partial \kappa} &lt; 0, \quad \frac{\partial e}{\partial \kappa} &lt; 0 ]</td>
<td>[ \frac{\partial b}{\partial \kappa} &gt; 0, \quad \frac{\partial e}{\partial \kappa} &lt; 0 ]</td>
</tr>
<tr>
<td>(6) ( c_e &gt; c_b ) (binding linear capacity constraint)</td>
<td>[ \frac{\partial b}{\partial \kappa} &gt; 0, \quad \frac{\partial e}{\partial \kappa} &gt; 0 ]</td>
<td>[ \frac{\partial b}{\partial \kappa} &gt; 0, \quad \frac{\partial e}{\partial \kappa} &lt; 0 ]</td>
</tr>
</tbody>
</table>

This brief analysis shows that a binding linear capacity constraint links both tasks of the manager through the maximum available working effort \( \kappa \). In equilibrium, the resulting working efforts for each task then depend on this \( \kappa \). We could include this interaction into the analysis of our paper, but that would shift the attention away from the initial research question – how does the introduction of environmental liability affect the quality of pollution reporting – toward the question of how the manager splits her working efforts in different scenarios.

A9: Normally distributed performance indicators

The assumption of uniformly distributed performance indicators \( \bar{x} \) and \( \bar{y} \) allows closed model solutions. We now assume these indicators to be normally distributed:

\[ \bar{x} \sim N(b, \pi) \]  

(A 18a)
\[
\tilde{y} \sim N(e, \varepsilon) \tag{A 18b}
\]

The analysis and the results of the no liability case, the socially optimal pollution level and the case of strict liability with and without manipulation and reputation loss do not change because \(E[\tilde{x}] = b\) and \(E[\tilde{y}] = e\) still hold in analogy to uniformly distributed performance indicators. For all of these cases, only the expected value of the performance indicators matters. Therefore, it is only the results under a negligence rule that have to be reconsidered.

With normally distributed performance indicators, the probability of being held liable for environmental damage is:

\[
P(\tilde{y} > y_{opt}) = 1 - F\left(y_{opt} = e_{max} - \frac{d}{c_e} \right) = 1 - \phi \left( \frac{e_{max} - \frac{d}{c_e} - e}{\varepsilon} \right) \tag{A 18c}
\]

Thus, shareholders’ expected utility is:

\[
EU^P = b - \alpha - \beta b - \gamma e - de \cdot \left( 1 - \phi \left( \frac{e_{max} - \frac{d}{c_e} - e}{\varepsilon} \right) \right) \tag{A 18d}
\]

The manager’s expected utility remains unchanged since \(E[\tilde{x}] = b\) and \(E[\tilde{y}] = e\) and, therefore, the optimization’s constraints comply with equations (5), (6) and (7). Lagrange optimization reveals an implicit condition for individual optimal pollution levels in equilibrium

\[
c_e(-e^* + e_{max}) - \frac{de^*e}{2\varepsilon^2} \left( \frac{d}{c_e}(e^* + e_{max}) \right)^2 \frac{1}{\varepsilon \sqrt{2\pi}} - \frac{1}{2} d \cdot \text{erfc} \left[ \frac{-d c_e}{\varepsilon} - \frac{e^* + e_{max}}{\varepsilon} \right] \varepsilon \sqrt{2\pi} = 0 \tag{A 18e}
\]

and the principal’s expected utility that depends on the measurement error, \(\varepsilon\), and the pollution level in equilibrium, \(e^*\),

\[
EU^P(e^*(\varepsilon), \varepsilon) = \frac{1}{2} \cdot \frac{1}{c_b} \cdot \frac{c_e}{2} (e_{max} - e^*)^2 - de^* \left( \frac{1}{2} \right) \varepsilon \sqrt{2\pi} \tag{A 18f}
\]
This system of equations cannot be solved analytically because of the complementary error function, which stems from the normal distribution. A numerical solution with sample values for the distinct parameters provides insights to the course of the curve in principle. Assume $c_e = 1$, $d = 2$, $e_{\text{max}} = 5$ and $c_b = 1/100$. The individual optimal pollution level in equilibrium depending on the measurement precision can be gathered from Figure 4.

Similar to the model with uniformly distributed performance indicators, the manager reduces emission levels below the social optimum with normally distributed performance indicators as well, given that the measurement error is not too large. Under normally distributed performance indicators, there is a special feature for large measurement errors: if $\varepsilon$ becomes too high, companies consider the corresponding environmental performance indicator $\hat{y}$ to be largely uninformative and thus not sufficient to prevent them from being held liable, so they choose high pollution levels – even higher than the socially optimal level – to at least save on costs for pollution-reduction activities.

**Figure 4**: Pollution levels with uniformly and normally distributed performance indicators

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$c_b \ll c_e$ to ensure positive values for $EU^P$. The whole compensation contract is based on punishing the manager. High compensation independent of environmental performance is thus necessary for positive values of $EU^P$. That looks nicer, but is not important for the model’s results and their interpretation.
This effect is also reflected in the shareholders’ expected utility function in Figure 5, even though it is hardly visible. There is a very slight increase in shareholder’s expected utility for high values of $\varepsilon$, which stems from savings from reduced pollution-reduction activities. Nevertheless, even for the most imprecise measurement technique, i.e. $\varepsilon = e_{\max} - \left( \frac{d}{c_e} \right)$, and the highest possible pollution level, i.e. $e = e_{\max}$, shareholders’ expected utility is always lower than for the most precise measurement technique, i.e. $\varepsilon \to 0$. Thus, the finding that shareholders would benefit from a more precise measurement technique (which we derived with uniformly distributed parameters) holds under normally distributed parameters as well. To obtain the results for pollution report manipulation under a negligence regime, once again, only the probability of exceeding the due diligence threshold has to be adjusted. Figure 6 depicts the equilibrium pollution level depending on the measurement error for the different cases.

\[ EU^p(e = e_{\text{opt}}, \varepsilon = 0) = \frac{1}{2c_b} - \frac{d^2}{2c_e} - \frac{1}{2} d \left( -\frac{d}{c_e} + e_{\max} \right) > \frac{1}{2} c_b - d e_{\max} \cdot \text{erfc} \left( \frac{d}{\sqrt{2} (d - c_e e_{\max})} \right) = EU^p(e = e_{\max}, \varepsilon = e_{\text{opt}}) \text{ holds for all } c_b > 0, c_e > 0, d > 0, e_{\max} > 0, e_{\max} > d/c_e. \]
The basic results remain unchanged: when the manager is able to manipulate the reports, she will do so, and that yields higher real pollution levels. Reputation losses that are tied to incorrect reporting will mitigate the manipulation activity; however, shareholders will have to accept some more units of real pollution to make manipulation less attractive to the manager.

Nevertheless, shareholders benefit from the manager’s manipulation of reports, because it reduces their likelihood of being held liable for environmental pollution. Figure 7 illustrates this effect (dashed line). A sufficiently high reputation loss counteracts this benefit and makes report manipulation unfavorable from the shareholders’ perspective (bold dashed line). Whether the reputation loss is large enough to make manipulation unattractive from the shareholders’ perspective also depends on the precision of the measurement technique (e.g. see dashed-dotted line).
**Figure 7:** Shareholders’ expected utility and measurement error under a negligence regime with normally distributed performance indicators

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**A10: The link between environmental and financial performance**

Introducing a link between financial and environmental performance in the form of

\[
E[\hat{x}] = b + k \cdot e
\]

(A 19a)

where \( k \) can either be greater than 0 (i.e. high pollution levels increase the company’s financial performance, e.g. when high-polluting processes increase productivity and, in turn, sales) or smaller than 0 (i.e. higher pollution levels decrease the company’s financial performance, e.g. when customers boycott the company’s products because of poor environmental performance). This affects shareholders’ as well as the manager’s expected utility and, thus, optimization constraints. The corresponding utility functions are summarized in Table A8.

Moreover, if the company’s financial performance is interpreted as a kind of expected benefit for society, it enters society’s expected cost function with a negative sign and, thus, affects the socially optimal pollution level:

\[
EC(e) = de + \frac{1}{2} c_e(e_{\text{max}} - e)^2 - (b + k \cdot e)
\]

(A 19b)
\[ e_{opt} = e_{max} - \frac{d}{c_e} + \frac{k}{c_e} \]  

(A 19c)

**TABLE A8:** The manager’s and shareholders’ expected utilities when financial and environmental performance are linked

<table>
<thead>
<tr>
<th>Manager’s expected utility</th>
<th>[ E^M = \alpha + \beta(b + k \cdot e) + ye - \frac{1}{2} c_b b^2 - \frac{1}{2} c_e (e_{max} - e)^2 ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>IR</td>
<td>[ \alpha + \beta(b + k \cdot e) + ye - \frac{1}{2} c_b b^2 - \frac{1}{2} c_e (e_{max} - e)^2 \geq 0 ]</td>
</tr>
<tr>
<td>IC 1</td>
<td>[ \beta - c_b b = 0 ]</td>
</tr>
<tr>
<td>IC 2</td>
<td>[ c_e (e_{max} - e) + \gamma + \beta k = 0 ]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shareholders’ expected utility</th>
<th>[ E^P = (b + k \cdot e) - (\alpha + \beta(b + k \cdot e) + ye) ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>No liability</td>
<td>[ E^P = (b + k \cdot e) - \alpha - \beta(b + k \cdot e) - ye - de ]</td>
</tr>
<tr>
<td>Strict liability</td>
<td>[ E^P = \begin{cases} (b + k \cdot e) - \alpha - \beta(b + k \cdot e) - ye - de \ (b + k \cdot e) - \alpha - \beta(b + k \cdot e) - ye - d \cdot e \cdot \left( 1 - \frac{y_{opt} - ye + \epsilon}{2\epsilon} \right) \end{cases} \text{ if } y \leq y_{opt} ]</td>
</tr>
<tr>
<td>Negligence</td>
<td>[ E^P = \begin{cases} (b + k \cdot e) - \alpha - \beta(b + k \cdot e) - ye - d \cdot e \cdot \left( 1 - \frac{y_{opt} - ye + \epsilon}{2\epsilon} \right) \text{ if } y &gt; y_{opt} \end{cases} ]</td>
</tr>
</tbody>
</table>

Whether the socially optimal pollution level is higher or lower than in the initial model depends on the sign of \( k \): if companies financially benefit from pollution \((k > 0)\), it is higher than before, and vice versa.

Lagrange optimization yields similar results for all three liability scenarios regarding the effect of \( k \): without any environmental liability, shareholders’ expected utility, the fixed salary parameter, \( \alpha \), and the pollution level in equilibrium all depend on \( k \). Whether \( e^* \) is higher or lower than before is again determined by the sign of \( k \).30 Without any environmental liability, \( y \) remains 0, so compensation is still independent of environmental performance. The manager’s effort for core business operations \( b^* \) in equilibrium is unaffected. Under strict liability and negligence,

30 Note that \( e^* \) cannot exceed \( e_{max} \), so even if \( k > 0 \), \( e^* \) remains in the same place, even though a manager would want to increase it. For \( k < 0 \) she will reduce it, because that enhances the company’s financial performance and, in turn, her compensation.
the same effects are observed: \( k \) has an impact on \( Eu_P, \alpha \) and \( e^* \), but not on \( b^* \). In addition, the main results of this research remain unaffected as shown below:

- \( e^* = e_{opt} \) under strict liability,
- \( Eu_P \) is independent of the measurement precision \( \varepsilon \) under strict liability,
- \( e^* \) is lower than or at maximum equals \( e_{opt} \) under negligence,
- \( Eu_P \) depends on \( \varepsilon \) under negligence and increases for more precise measurement.

When it is possible for the manager to manipulate the expected value of the environmental performance indicator \( \bar{y} \), she will do so and thus reduce her efforts to avoid environmental pollution. As a consequence, \( e^* \) increases under strict liability as well as under negligence. This has, in turn, an impact on the manager’s effort for core business operations \( b^* \), e.g. under strict liability:

\[
b^* = \frac{c_e + c_i - c_b dk + c_b k^2}{c_b (c_e + c_i + c_b k^2)} \quad (A\ 19d)
\]

Whether this effort \( b^* \) is greater or lower than in the situation without manipulation depends again on the sign of \( k \). If \( k > 0 \), then \( \frac{c_e + c_i - c_b dk + c_b k^2}{c_b (c_e + c_i + c_b k^2)} < \frac{1}{c_b} \) and so \( b^* \) with report manipulation is greater than without. That means that when financial performance increases with the pollution level, report manipulation reduces the manager’s effort for core business operations, because it is substituted by a higher pollution level. If \( k < 0 \), the opposite holds.

Nevertheless, also for this model extension the main results, i.e.

- the manipulation-reducing effect of reputation losses under strict liability and negligence
- and the shareholders’ potential benefit of report manipulation under negligence when there is no sufficient reputation loss

remain unchanged even when financial and environmental performance are linked.