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# Precision and Manipulation of Non-financial Information: The Curious Case of Environmental Liability

This paper develops a model showing how the environmental liability regime and the precision of the disclosed environmental performance indicator affect managers' incentives (1) to reduce *actual* pollution and (2) to manipulate the reported pollution. I assume a company with a separation of ownership and control which can be held liable for environmental damages and distinguish between a negligence regime and strict liability. The results suggest that if there is no manipulation but only a lack of precision of the disclosed environmental performance indicator, a negligence rule induces *lower* actual pollution levels than strict liability even though a negligence rule is considered to be more lenient. If managers are able to manipulate the disclosed environmental performance indicator, they will do so and *actual* pollution levels will generally increase. While manipulation makes it easier for shareholders to escape liability under a negligence regime, shareholders suffer from manipulation under strict liability due to higher actual pollution and higher expected damage compensation payments. Therefore, the manipulation level is higher under a negligence regime. My analysis contributes to the environmental performance and disclosure literature by showing that the liability regime is an important determinant affecting environmental reporting and actual pollution decisions.

**Key words:** Environmental performance; Environmental liability; Manipulation; Precision; Environmental pollution; Performance measurement; EPI; Environmental reporting.

In recent years, the disclosure of *non-financial* information and environmental information in particular has become increasingly important to investors and academics (e.g., Perez-Batres *et al.*, 2012; Cormier and Magnan, 2015; Guenther *et al.*, 2016). The institutional setting may significantly influence reporting incentives (Ewert and Wagenhofer, 2011). Important components of this

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institutional setting are legal rules. In an environmental context, it is above all the environmental liability regime that builds the legal framework for companies' environmental pollution behaviour. Its goals are mainly 'to make polluters pay for the environmental costs of their activities, to compensate innocent victims, to protect the environment [...]' (Brunnée, 2004, p. 351). Thus, it might work as an instrument to incentivize companies to reduce their environmental pollution, rationally anticipating that they might have to pay damage compensation (Shavell, 2007). This paper explicitly asks how the environmental liability regime affects managers' incentives (1) to reduce *actual* pollution and (2) to report the environmental pollution level truthfully, given that victims of environmental damage use disclosed environmental information in litigation.

The Volkswagen diesel scandal is a prime example of severe consequences suffered through manipulated non-financial information. Besides enormous reputation loss (Kottasova, 2015), high (expected) damage compensation payments (Viswanatha *et al.*, 2017), decreasing market value (Gomez, 2016), and a scandal-induced CEO turnover and prosecution (Roberts and Rogers, 2018), researchers estimate serious associated human health impacts and costs (Chossière *et al.*, 2017).

While it is not clear whether Volkswagen will be liable for these health damages, other companies such as ArcelorMittal (US Department of Justice, 2017) and Pacific Gas and Electric, known from the popular movie *Erin Brockovich*, have already been sued for environmental damages.

Companies are liable for the environmental pollution<sup>1</sup> they cause in many countries, such as in EU Member States and in the US (European Commission, 2016; Sigman, 2010). Although liability rules require courts to be able to observe the *actual* pollution level, they may find it hard to do so (Goldsmith and Basak, 2001). For instance, European regulation has required greenhouse gas (GHG) emissions to be monitored and reported since 2008 (EU Directive 2003/87/EC),<sup>2</sup> but there is only limited precision of technical measurement tools (IPCC, 2006; Virtanen *et al.*, 2013; Unerman and Chapman, 2014). Therefore, I explicitly consider the fact that there is a lack of precision in measuring pollution levels.

The model in this paper addresses two characteristics of environmental reporting quality: the *precision* of pollution measurement and managers' incentives for *manipulation* of the reported information. Precision refers to the accuracy of technical measurement (its noise) and is specified in my model. While managers may generally find it difficult to influence the precision of technical devices, they may well be able to manipulate reported environmental performance indicators by reporting pollution levels that are lower than the actual levels (shifting the mean). Thus, reporting manipulation and actual pollution are

<sup>1</sup> For instance, water pollution, soil contamination, or air pollution. Pollution reduction is an urgent goal on the political agenda (e.g., European Commission, 2017). Environmental liability has become an important instrument to reduce pollution. Other approaches to reducing pollution are bans or regulated trade on pollution certificates.

<sup>2</sup> European Parliament (2003), EU Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC.

managerial choice variables in my model while the precision of the environmental performance indicator (EPI) is determined by state-of-the-art measurement technology and is, therefore, exogenous.

I analyze how environmental liability rules affect managers' incentives to effectively reduce pollution and to manipulate EPIs dependent on a given level of measurement precision. Three scenarios exist: (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 always held liable when its pollution causes damage. With a negligence regime, the company is only held liable if pollution causes damages and, *additionally*, if the company acted negligently, that is, if it failed to meet the 'standard of due care' according to legal rules. Courts decide on negligence *ex post* based on the available information, for instance a company's reported pollution information. Due to this additional (information) requirement, a negligence regime is considered to be more lenient than strict liability. Polluting companies can be held liable under strict liability or under a negligence regime in both the EU and the US.

In companies with separation of ownership and control the agency problem between shareholders and managers has to be considered. In my model, only managers are able to observe the *actual* pollution level. Shareholders, however, may be negatively affected by a higher probability of bearing the company's damage compensation payments. As a result, shareholders rationally set up a compensation contract that provides monetary rewards to the manager for improving environmental performance (Deegan and Islam, 2012; Strandberg, 2013), that is, for reducing pollution levels. The manager can increase environmental performance by striving for higher effort levels to reduce pollution. The effort level is not contractible. The compensation contract is based on an EPI.<sup>3</sup> In a model extension, I also analyze the case where the manager is also able to manipulate the EPI.

I find that the liability regime strongly influences incentives for reducing *actual* pollution levels and EPI manipulation. Results also depend on the precision of the EPI measurement. The case of no liability is straightforward: there is no need for manipulation then, and pollution levels are high. EPI measurement precision is irrelevant.

Without the possibility of EPI manipulation, a negligence regime induces lower actual pollution levels than a strict liability regime even though strict liability is meant to be the tougher liability regime. The reason for this is that strict liability is based on actual damages and, thus, actual pollution—regardless of the EPI's precision—whereas under a negligence regime companies can only be held liable for reported pollution levels exceeding the standard of due care. Lower precision of the EPI increases type-1 errors—reported pollution is high even though actual pollution is low—which, in turn, induces the manager to *lower* actual pollution levels.

<sup>3</sup> I use the terms environmental performance indicator (EPI), pollution report, and pollution indicator interchangeably.

If the manager is able to manipulate the EPI, the *actual* pollution level will generally increase. While manipulation makes it easier for shareholders to escape liability under a negligence regime, shareholders tend to suffer from manipulation under strict liability due to higher actual pollution levels and higher expected damage compensation. Therefore, if manipulation is possible, a negligence regime aligns the interest of shareholders and managers—the *more* precise the measurement technology gets, the more aligned the interest becomes—while they have divergent interests under strict liability. Consequently, there is *more* manipulation under a negligence regime than under strict liability. Note that without the separation of ownership and control, manager-shareholders would have no interest in manipulating the reported EPI under strict liability because only actual pollution, not the EPI, matters for damage compensation. The incentives for EPI manipulation depend to a crucial extent on both the liability regime and the separation of ownership and control. This insight may be of interest to policymakers.

To the best of my knowledge, this is the first paper that analyzes the delicate interaction between environmental liability rules, pollution-reporting incentives, and actual pollution. It contributes to different strands of literature. First and most importantly, my model adds surprising insight to the link between environmental performance measurement and actual environmental performance. This literature stresses that environmental performance measures with a low validity will negatively affect motivation, which in turn endangers environmental performance (e.g., Virtanen *et al.*, 2013; Lisi, 2015). I find that under a negligence regime, a less precise EPI might induce the manager to *lower* actual pollution levels and, thus, a better environmental performance.

Second, the paper contributes to the literature that addresses the link between environmental performance and environmental disclosure.<sup>4</sup> Li *et al.* (1997) show that companies with a sufficiently good environmental performance will report environmental liabilities truthfully while poorly performing companies will not do so if there is uncertainty surrounding the existence and size of the environmental liabilities created, or if there are disclosure costs involved. Legitimacy theory, however, suggests that poor environmental performers show higher levels of discretionary environmental disclosure due to greater political and social pressures (Patten, 2002). I contribute to this discussion by explicitly incorporating environmental liability and the separation of ownership and control. In the process, I endogenize shareholders' expected liability costs, which are exogenous in the Li *et al.* (1997) model. Roughly in line with Li *et al.* (1997), my paper suggests a positive association between truthful environmental reporting and low actual pollution levels, albeit based on a moral hazard problem. Moreover, I find that the above association is influenced by the liability regime, the separation of

<sup>4</sup> Most of the environmental reporting literature is empirical and ignores the impact of the environmental liability regime on reporting choices (e.g., Cormier *et al.*, 2005; Kolk *et al.*, 2008; Sullivan and Gouldson, 2012; Stanny, 2013; Matisoff *et al.*, 2013; Lu and Abeysekera, 2014; Matsumura *et al.*, 2014; Clarkson *et al.*, 2015; Griffin *et al.*, 2017).

ownership and control, and the precision of pollution measurement, all of which Li *et al.* (1997) do not consider in their model.

Third, the paper is relevant to the literature that analyzes the real effects of disclosure, (e.g., Kanodia, 2006; Beyer and Guttman, 2012; Kanodia and Sapra, 2016; Dutta and Nezlobin, 2017). However, while this literature generally emphasizes the real effects of financial information on investment efficiency or risk management in the absence of liability issues, my paper shows how non-financial information affects actual environmental pollution under explicit consideration of the environmental liability regime.

Fourth, I contribute to the law and economics literature, which has not yet analyzed how liability rules affect managers' incentives for manipulation of reported information (e.g., Shavell, 2007; Endres *et al.*, 2015). Polinsky and Shavell (2012) discuss which type of disclosure regime—voluntary or mandatory—regarding product risks is socially beneficial. They find that mandatory disclosure rules are more valuable to customers, while the company's incentives to acquire information are stronger under voluntary disclosure. However, Polinsky and Shavell (2012) ignore liability rules, owner–manager conflicts of interest and the possibility of manipulation.

Finally, my paper enriches environmental accounting research in cross-country settings in general by providing model theoretical-based justification to incorporate the environmental liability regime when analyzing companies' non-financial reporting choices. In this regard, my work is in line with Ewert and Wagenhofer's (2011) claim that the institutional setting may significantly influence reporting incentives. Hartmann *et al.* (2013) support this view, especially for environmental concerns such as GHG emissions. Institutional characteristics that have already been considered in empirical environmental and CSR reporting research include the introduction of mandatory reporting requirements (e.g., Frost, 2007), the national business system and the strength of investor and employment protection laws (e.g., Jackson and Apostolakou, 2010), the quality of the legal environment (Worldbank's 'rule of law' measure), as well as the distinction in common and code law countries which proxies shareholder versus stakeholder orientation of the country in which the company is domiciled (e.g., Simnett *et al.*, 2009; Luo, 2019). The environmental liability regime has so far been ignored but the results of my model suggest that it impacts managerial reporting choices and real corporate decisions strongly. Incorporating this country-specific institutional characteristic into (empirical) environmental accounting studies may have the potential to affect prior insights on institutional determinants of environmental accounting. For instance, differences in companies' environmental reporting behaviour attributed to their location in common or code law countries could be blended by the impact of potentially different environmental liability regimes in those countries. Code law countries are often assumed to be stakeholder-orientated and, therefore, companies in those countries are expected to be more eager to fulfil stakeholder needs compared to companies in shareholder-orientated countries where only shareholder value and pure financial outcomes count. Thus, in stakeholder-orientated countries better

corporate environmental performance would be expected. If a code law country has installed a negligence regime for environmental pollution, my model suggests lower environmental pollution as compared with a strict liability (potentially common law) country. The assumed stakeholder orientation as well as the negligence regime in the considered country both lead to lower environmental pollution but which of both effects prevails is not yet determined. Careful consideration of the specific institutional framework is then needed to disentangle the effects of these two different institutional characteristics in order to be able to evaluate the impact of each of them.

## ENVIRONMENTAL LIABILITY IN THE EU AND THE US

Strict liability implies that a company is held liable when the pollution it causes results in damage. Under a negligence regime, a company is only held liable if the pollution it causes results in damage *and* it acted negligently, that is, the company failed to meet the ‘standard of due care’ according to legal rules. Courts need to decide on whether the standard of due care has been met. As it is difficult to gather reliable environmental information for outsiders (Goldsmith and Basak, 2001), they will rationally use information provided in the company’s pollution report.<sup>5</sup> Under strict liability, the pollution report does not matter because damage compensation is simply based on the occurrence of damages. Since the (information) requirements for obtaining damage compensation are more restrictive under negligence, strict liability is thought to provide stronger incentives for preventing environmental pollution.

In the EU, environmental liability is laid down in Directive 2004/35/EC,<sup>6</sup> which has been amended slightly three times (2006/21/EC; 2009/31/EC; 2013/30/EU).<sup>7</sup> Companies face strict liability for environmental pollution when carrying out dangerous occupational activities such as waste management, the treatment of

<sup>5</sup> Even if it is assumed that courts or public prosecutors gather information on their own for a certain lawsuit, it is likely that this information is at least highly correlated—if not identical—with the information the company provides, assuming truthful reporting and the usage of a state-of-the-art measurement technology. Then, both parties (company and court) have to rely on the same measurement technology that is impaired by a certain imprecision. Thus, similar measurement results and EPIs can be expected *ex ante* if the court collects the information on its own.

<sup>6</sup> European Parliament (2004), EU Directive 2004/35/EC of the European Parliament and of the Council of 21 April 2004 on environmental liability with regard to the prevention and remedying of environmental damage.

<sup>7</sup> European Parliament (2006), EU Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries and amending Directive 2004/35/EC; European Parliament (2009), EU Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006; European Parliament (2013), EU Directive 2013/30/EU of the European Parliament and of the Council of 12 June 2013 on safety of offshore oil and gas operations and amending Directive 2004/35/EC.

dangerous substances, activities under the Industrial Emissions Directive 2010/75/EU,<sup>8</sup> or the transport of dangerous or polluting goods (European Commission, 2016). Companies that do not carry out dangerous activities can only be held liable for environmental damages if they acted negligently (European Commission, 2016).

In the US, environmental laws exist at both the federal and state level. State law applies to environmental damages or sites that are not covered by federal law (Sigman, 2010, p. 292). At the federal level, the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) assigns strict liability to the polluting company for costs associated with cleaning up sites contaminated by hazardous wastes (42 U.S. Code § 9607,<sup>9</sup> see also Larson, 2005, pp. 547–52). At the state level, Sigman (2010, p. 293) reports strict liability in some states (e.g., California, Florida, and Missouri) and a negligence regime in others (e.g., Alabama, Colorado, and Idaho).

Therefore, in both the EU and the US companies can be held liable under either strict liability or a negligence regime, depending on the risk level of professional activity in the EU and on the law applied in the US. Hence, I analyze both liability regimes.

## MODEL ASSUMPTIONS

I analyze a model with risk-neutral actors and a zero discount rate for riskless assets.<sup>10</sup> The shareholders (principal) of a company delegate the decision regarding actual environmental pollution to a professional manager (agent). The shareholders (and other parties, such as courts) are unable to directly observe or control the managerial effort to influence the pollution level. The manager suffers a disutility from reducing pollution. This disutility can take the form of direct costs for pollution reduction as the installation of new filters or R&D expenses for the development of less polluting processes which all debit the manager's budget that could be spent on something else. Moreover, it also covers indirect aspects, for example, foregone leisure time or disutility because the manager does not like performing the task. This disutility is not verifiable by the court but is known to the shareholders.

<sup>8</sup> European Parliament (2010), EU Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control).

<sup>9</sup> US Code (1980), §9607 et seq. 42 U.S. Code Chapter 103: Comprehensive Environmental Response, Compensation, and Liability Act.

<sup>10</sup> Introducing a positive discount rate does not alter the results. Such a positive discount rate could incorporate the fact that environmental damages usually take effect with a considerable time delay. For instance, probably the most severe consequence of GHG emissions, climate change, is predicted to take its full effect 'by the late 21st century and beyond'. (IPCC, 2014, p. 8). Nevertheless, it can be modelled as a constant factor that discounts the maximum damage  $D$  and, thus, does not change the following analysis.

In line with fundamental principal–agent analyses (Holmström and Milgrom, 1991; Feltham and Xie, 1994), shareholders offer the manager a compensation contract based on a verifiable and, thus, contractible indicator for the EPI to align their interests. The EPI is called  $\tilde{y}$  and is a stochastic variable. It depends on the manager’s decision  $p$  with regard to the company’s pollution level. The EPI  $\tilde{y}$  is uniformly distributed:  $\tilde{y} \sim \text{uniform}(p - \varepsilon, p + \varepsilon)$ , with  $0 \leq \varepsilon \leq p \leq p_{max}$  and an expected value  $E[\tilde{y}] = p$ . The distribution parameter  $\varepsilon$  reflects the (lack of) precision<sup>11</sup> associated with the EPI. In the basic model, the manager discloses the EPI  $\tilde{y}$  mandatorily and truthfully. This assumption is relaxed in the extended model. Figure 1 illustrates the timeline of events.

The compensation contract is non-linear.<sup>12</sup> Following Holmström (1979), the first-best solution can be achieved with a simple hurdle rate contract that rewards the manager with a lump sum payment if the performance measure exceeds a certain threshold value. Hence, in my model the manager receives a bonus  $\bar{s}$  if the EPI indicates an environmental pollution level below the threshold value set by the shareholders, that is if  $y \leq y_s$ . Otherwise, the manager receives no bonus. The bonus  $\bar{s}$  needs to be non-negative due to manager’s limited liability.

$$s(\tilde{y}) = \begin{cases} \bar{s} & \text{if } y \leq y_s \\ 0 & \text{if } y > y_s \end{cases} \quad \text{with } \bar{s} \geq 0. \tag{1}$$

Since the EPI is distributed uniformly, the probability that the EPI will be lower than the shareholders’ threshold value  $y_s$  equals

$$\text{Prob}(y \leq y_s) = \frac{y_s - (p - \varepsilon)}{2\varepsilon} = \frac{y_s - p + \varepsilon}{2\varepsilon}. \tag{2}$$

The manager’s decision regarding the company’s pollution level  $p$  affects the probability of environmental damage occurrence:  $ED = \text{Prob}(p)D = \frac{p}{p_{max}}D$ . If the manager does nothing to reduce pollution ( $p = p_{max}$ ), the expected environmental

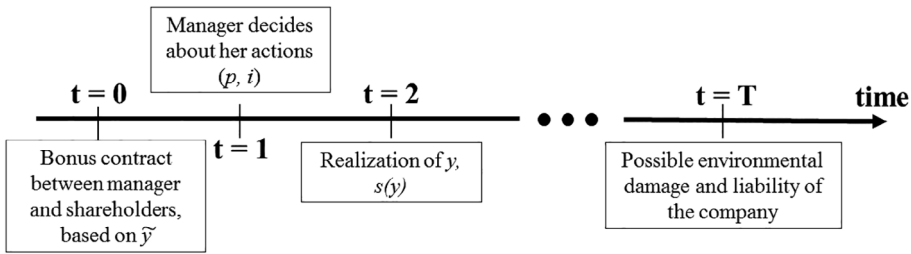
<sup>11</sup> According to Goldsmith and Basak (2001), this imprecision is not only due to technical equipment characteristics, but also to stochastic environmental events that might have nothing to do with a manager’s actual effort to reduce pollution levels but which are still kept by the EPI. Hence, I assume that managers are able to assess the precision of their EPIs, but for outsiders such as the court the imprecision  $\varepsilon$  is not verifiable.

<sup>12</sup> Note that it is not the aim of this paper to develop an optimal compensation contract, but rather to analyze the impact of EPI characteristics on pollution reduction incentives under different liability regimes in as realistic as possible settings. Anecdotal evidence supports the approach of applying very simple compensation contracts. For instance, Lufthansa Group and BMW Group include indicators for environmental protection level (Lufthansa Group Annual Report, 2017) or GHG emissions reductions (BMW Group Annual Report, 2017) in the variable remuneration of directors. Shell includes metrics for GHG management in a scorecard which forms the basis for bonus payments and also embeds energy transition into the CEO’s personal performance targets (Shell Annual Report, 2017). Moreover, a robustness check is included in the Appendix. There a linear compensation scheme is analyzed. Basic results do not change.



FIGURE 1

TIMELINE OF EVENTS



$\tilde{y}$  - Environmental performance indicator     $p$  - Company's actual environmental pollution level  
 $s(\tilde{y})$  - Manager's salary based on  $\tilde{y}$          $i$  - Manager's effort for reporting manipulation

damage reaches its maximum,  $ED = D$ . In the case of no pollution,  $p = 0$ , no damage is expected. This maximum environmental damage  $D$  can be understood as a monetarily quantifiable damage that was caused by a certain company's pollution, for example, costs for repairing a damaged ecosystem in a polluted river.

To keep the analyses simple and focused on the most important issues, I assume risk neutrality of both actors (e.g., Segerson and Tietenberg, 1992; Shavell, 2007). Thus, in the absence of environmental liability, the shareholders' and the manager's respective utility functions are reflected in the following:

$$U^S = -s(\tilde{y}) \tag{3}$$

$$U^M = s(\tilde{y}) - \frac{1}{2}c_p(p_{max} - p)^2. \tag{4}$$

The shareholders' utility,  $U^S$ , is defined by the manager's remuneration,  $s$ , which depends on the environmental performance measure  $\tilde{y}$ .<sup>13</sup> The manager's utility,  $U^M$ , is defined by their salary,  $s$  (based on the EPI), minus the disutility for their effort to reduce pollution below the maximum level  $p_{max}$ . The cost function assumes increasing marginal costs

<sup>13</sup> The shareholder's utility function is non-positive by construction. That does not seem realistic: why should a shareholder engage in a business if the utility is negative (corner solutions excluded)? This is a model feature that directly stems from the focus on a single managerial task, the reduction of environmental pollution. In reality, managers have several tasks. Including an independent second task that covers manager's 'business as usual activity' and which leads to a sufficiently positive profit increases shareholders' utility (e.g., by an increase in share price) above zero. Such an independent second task does not alter the results of this paper. Consider the respective robustness check in the Appendix.

for reducing pollution: the disutility depends quadratically on the particular effort made. It is expressed in monetary terms by the disutility parameter  $c_p$ , with  $c_p > 0$ . In order to obtain interior solutions, I assume that the manager's costs when avoiding all pollution will exceed the maximum expected damages,  $c_p p_{max}^2 > Prob(p = p_{max})D = D$ . Otherwise, zero pollution would be socially desirable which is apparently not the case in reality. Without loss of generalization, I assume that the manager has a zero reservation utility.<sup>14</sup>

### *Environmental Liability*

The company may be held liable for environmental damages, depending on the liability setting. I analyze how strict liability and a negligence rule affect the manager's choice to reduce actual pollution and to correctly report pollution levels. I follow the law and economics literature and assume that the standard of due care is defined by the socially optimal pollution level (Shavell, 2007), which I will derive in the next section. The court decides whether due care has been met based on the company's verifiable pollution report,  $\tilde{y}$ . Under both liability regimes, the company has sufficient assets to pay for damage compensation.

The manager is not held liable. This assumption is realistic due to the 'business judgement' rule and the fact that the manager's assets are usually limited.<sup>15</sup> I 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, there would effectively be no liability. I analyze this no liability case below.

To test the robustness of the results obtained under these assumptions, some seemingly crucial ones are relaxed. Therefore, I analyze the impacts of a second managerial task, an alternative form of the compensation contract, and a normally distributed EPI. Moreover, the model is also extended by reputation losses either due to high EPI values or EPI manipulation. These sensitivity analyses are summarized in the Appendix.

<sup>14</sup> This assumption implies that the manager is indifferent between no pollution reductions at all and the interior solutions obtained in the following analyses. In both cases they expect a utility of zero in equilibrium (due to the design of the compensation scheme and their optimal answer to that, or due to the zero reservation utility they receive if they do nothing to reduce the pollution, respectively). Reality does not support the corner solution of no effort to reduce pollution at all. There is broad evidence on increasing pressure from various stakeholders companies face (e.g., Fornaro *et al.*, 2009; Guenther *et al.*, 2016). Hence, it can be assumed that if the responsible manager does nothing to reduce a company's environmental pollution at all, an additional penalty will be imposed on them. Then, they are not indifferent between the interior optimal solution  $p^*$  and the corner solution of a maximum pollution level  $p_{max}$  but will choose the interior solution. See Appendix A4 for a more comprehensive evaluation.

<sup>15</sup> Environmental law in the EU and the US defines the liability of the company, not the management (see, e.g., 2004/35/EC, Art. 8). Moreover, the 'business judgement' rule makes it difficult to hold managers liable (Reinhardt *et al.*, 2008; Bricker, 2013; Told, 2015). But in principle, corporation law allows shareholders to ask managers for damage compensation if they violated their duties towards shareholders. In the Appendix, the model extension of managers' reputation loss due to high realizations of the EPI and EPI manipulation are analyzed. In a broad interpretation, such a reputation loss can also be understood as a kind of personal liability of the manager. However, basic results do not change.

MODEL ANALYSIS: THE ROLE OF EPI MEASUREMENT PRECISION UNDER DIFFERENT LIABILITY REGIMES

Initially, I focus *only* on an imprecise but truthfully reported EPI and ignore EPI manipulation. I first show the social optimum as a benchmark and then analyze the cases of no liability, strict liability, and a negligence regime.

*Socially Optimal Pollution Level*

The socially optimal pollution level is derived by minimizing the expected social cost function  $EC(p)$  (Shavell, 2007), which consists of the expected damages (expressed in monetary terms) from pollution and the manager's cost to reduce them:

$$EC(p) = Prob(p)D + \frac{1}{2}c_p(p_{max} - p)^2 = \frac{P}{p_{max}}D + \frac{1}{2}c_p(p_{max} - p)^2. \quad (5)$$

Optimization yields:

$$p_{opt} = p_{max} - \frac{d}{c_p} \quad \text{with} \quad d = \frac{D}{p_{max}} > 0. \quad (6)$$

I obtain a positive interior social optimum,  $p_{opt} > 0$ , since I assume  $c_p p_{max}^2 > D$  or  $c_p p_{max} > d$ , respectively. The socially optimal pollution level decreases in the case of higher damages,  $D$ , and lower costs to reduce pollution,  $c_p$ .

*No Environmental Liability*

Regardless of the liability regime to be analyzed, the shareholders' expected utility depends on the EPI  $y$ . With the probability  $Prob(y \leq y_S)$ , shareholders need to pay a bonus  $\bar{s}$ ; with the probability  $Prob(y > y_S)$ , no bonus payment is made. Employing (2), the shareholders' expected utility can be defined as

$$EU^s = -\bar{s} \cdot \left( \frac{y_S - p + \varepsilon}{2\varepsilon} \right) - 0 \cdot \left( 1 - \frac{y_S - p + \varepsilon}{2\varepsilon} \right) - \text{expected environmental damage compensation}. \quad (7)$$

Equation (7) can be adjusted to the particular analyzed liability regime by inserting the corresponding expected environmental damage compensation payments. With no effective environmental liability regime, this expected compensation payment is zero. Thus, shareholders maximize

$$EU^s = -\bar{s} \cdot \left( \frac{y_S - p + \varepsilon}{2\varepsilon} \right). \quad (8)$$

Analogously, the manager's expected utility results in

$$EU^M = \bar{s} \cdot \left( \frac{y_S - p + \varepsilon}{2\varepsilon} \right) + 0 \cdot \left( 1 - \frac{y_S - p + \varepsilon}{2\varepsilon} \right) - \frac{1}{2} c_p (p_{max} - p)^2. \quad (9)$$

The manager's incentive compatibility constraint is derived from

$$\frac{\partial EU^M}{\partial p} = \frac{-\bar{s}}{2\varepsilon} + c_p (p_{max} - p) = 0. \quad (10)$$

From (10) I derive the manager's reaction function dependent on the bonus  $\bar{s}$ :

$$p(\bar{s}) = p_{max} - \frac{\bar{s}}{2\varepsilon c_p}. \quad (11)$$

Given a zero reservation utility, the manager's participation constraint in equilibrium is defined by

$$EU^M = 0 = \bar{s} \cdot \left( \frac{y_S - p + \varepsilon}{2\varepsilon} \right) - \frac{1}{2} c_p (p_{max} - p)^2. \quad (12)$$

Inserting the manager's reaction function from (11) into (12), the target level  $y_S$  dependent on the bonus  $\bar{s}$  is obtained:

$$y_S(\bar{s}) = p_{max} - \varepsilon - \frac{\bar{s}}{4\varepsilon c_p} \text{ for } \bar{s} \neq 0. \quad (13)$$

Inserting the manager's reaction function (11) and the target level in (13) into (8), I obtain the shareholders' expected utility dependent on the bonus  $\bar{s}$ :

$$EU^S = -\bar{s} \cdot \left( \frac{\left( p_{max} - \varepsilon - \frac{\bar{s}}{4\varepsilon c_p} \right) - \left( p_{max} - \frac{\bar{s}}{2\varepsilon c_p} \right) + \varepsilon}{2\varepsilon} \right). \quad (8a)$$

Setting the first partial derivative with respect to  $\bar{s}$  zero yields an optimal bonus of zero,  $\bar{s}^* = 0$ . The threshold value  $y_S^*$  cannot be derived from (10) because this reaction function excludes  $\bar{s}^* = 0$ . However, since the no-liability case makes the reduction of pollution irrelevant, shareholders grant no bonus and do not (need to) define a threshold value for the EPI.

The manager's response to a bonus  $\bar{s}^* = 0$  is maximum pollution (see reaction function (11)):

<sup>16</sup> For a bonus of zero,  $\bar{s} = 0$ , the question of a threshold that defines when the bonus is paid becomes irrelevant.

TABLE 1

RESULTS IN THE CASE OF NO ENVIRONMENTAL LIABILITY

Actual environmental pollution level	$p^* = p_{max}$
Bonus	$\bar{s}^* = 0$
Expected utility of shareholders	$EU^s = 0$

$$p^* = p_{max}$$

The resulting shareholder utility in equilibrium is then  $EU^s = 0$ . Expected environmental damages reach the maximum level  $Prob(p = p_{max})D = D$ . Table 1 summarizes these results.

*Strict Liability*

In this scenario, the company or its shareholders, respectively, have to pay damage compensation whenever damages occur, regardless of what the EPI indicates. Shareholders will consider expected damage payments:

$$EU^s = -\bar{s} \cdot \left( \frac{y_S - p + \varepsilon}{2\varepsilon} \right) - \frac{p}{p_{max}} D = -\bar{s} \cdot \left( \frac{y_S - p + \varepsilon}{2\varepsilon} \right) - dp. \tag{14a}$$

The manager's expected utility is not affected by the liability regime. Thus, I can take into account the manager's reaction function  $p(\bar{s})$  according to (11), and may then write:

$$EU^s = -\bar{s} \cdot \left( \frac{y_S - p_{max} + \frac{\bar{s}}{2\varepsilon c_p} + \varepsilon}{2\varepsilon} \right) - d \left( p_{max} - \frac{\bar{s}}{2\varepsilon c_p} \right). \tag{14b}$$

Inserting the threshold level function (13) into (14b) and setting the first partial derivative with respect to  $\bar{s}$  zero yields the optimal bonus

$$\bar{s}^* = 2d\varepsilon$$

and specifies the threshold value of the EPI according to (13):

$$y_S^* = p_{max} - \varepsilon - \frac{d}{2c_p}$$

The less precise the EPI (the higher  $\varepsilon$  is), the higher the potential bonus and the lower the target pollution level. If the EPI is imprecise, shareholders have to facilitate the accessibility of the bonus to incentivize managers to reduce actual pollution. The manager responds to the bonus  $\bar{s}^* = 2d\varepsilon$  by providing the socially optimal pollution level (see (11)):

TABLE 2

RESULTS UNDER STRICT LIABILITY

Actual environmental pollution level	$P^* = P_{max} - \frac{d}{c_p} = P_{opt}$
Bonus	$\bar{s}^* = 2d\epsilon$
Threshold value of the EPI	$y_S^* = P_{max} - \epsilon - \frac{d}{2c_p}$
Expected utility of shareholders	$EU^S = \frac{d(d-2c_p P_{max})}{2c_p}$

$$P^* = P_{max} - \frac{d}{c_p} = P_{opt}$$

The shareholders' expected utility in equilibrium is defined by  $EU^S = \frac{d(d-2c_p P_{max})}{2c_p}$ . The results are summarized in Table 2.

The intuition is that shareholders bear the full cost of environmental damages and, thus, design the compensation contract in such a way that the manager fully internalizes damage payments, choosing the socially optimal pollution level  $p_{opt}$ . Another interesting implication of the results in Table 2 is that the lack of precision of the EPI,  $\epsilon$ , is not of interest to the shareholders. Only expected damages matter.

RESULT 1: (a) *Strict liability provides efficient incentives to reduce actual pollution.* (b) *The precision of the EPI is then irrelevant.*

*Negligence Rule*

Under a negligence rule, the company is only held liable if the pollution it causes results in damage *and* it failed to meet the standard of due care defined by the social optimum (Shavell, 2007):<sup>17</sup>

$$y_{opt} = P_{opt} \tag{15}$$

When damage occurs, the company will only be held liable if the EPI indicates pollution levels above  $y_{opt}$ . Otherwise there is no liability. The shareholders' utility function then has two sections:

$$U^S = \begin{cases} -s(\tilde{y}) & \text{if } y \leq y_{opt} = P_{opt} = P_{max} - \frac{d}{c_p} \\ -s(\tilde{y}) - Prob(p) \cdot D & \text{if } y > y_{opt}. \end{cases} \tag{16}$$

I proceed with the analysis in three steps. First, I look at the case where shareholders make sure that liability is ruled out, meaning that the first section of

<sup>17</sup> Otherwise a negligence rule is likely to induce excessive or suboptimal levels of care to decrease pollution (Shavell, 2007).

TABLE 3

RESULTS UNDER A NEGLIGENCE RULE, GIVEN THAT LIABILITY IS RULED OUT:  
 $(\text{Prob}(y > y_{opt}) > 0)$

Actual environmental pollution level	$p^* = p_{max} - \frac{d}{c_p} - \varepsilon < p_{opt}$
Bonus	$\bar{s}^* = 2\varepsilon(d + c_p\varepsilon)$
Threshold value of EPI	$y_S^* = p_{max} - \frac{3\varepsilon}{2} - \frac{d}{2c_p}$
Expected utility of shareholders	$EU^s = -\frac{(d + c_p\varepsilon)^2}{2c_p}$

(16) becomes relevant ( $\text{Prob}(y \leq y_{opt}) = 1$ ). Second, I focus on the negligence case where liability is possible ( $\text{Prob}(y > y_{opt}) > 0$ ). Third, I derive the global optimum.

*Liability is ruled out* ( $\text{Prob}(y \leq y_{opt}) = 1$ ) In this case the EPI  $\tilde{y}$  never indicates negligence ( $\text{Prob}(y \leq y_{opt}) = 1$ ). Recall that the EPI is noisy and uniformly distributed between  $p - \varepsilon$  and  $p + \varepsilon$ . To rule out liability for sure, the highest possible realization of  $\tilde{y}$ , that is  $p + \varepsilon$ , must not exceed the threshold  $y_{opt}$ :

$$p + \varepsilon \leq y_{opt} \Leftrightarrow p + \varepsilon \leq p_{max} - \frac{d}{c_p}. \tag{17}$$

It is already known that the highest possible pollution level will be realized when there is no liability. In this case, it is the highest pollution level not exceeding the standard of due care:

$$p^* = p_{max} - \frac{d}{c_p} - \varepsilon.$$

The pollution level is lower than under strict liability by the amount  $\varepsilon$ . Employing (11) and (13), the bonus  $\bar{s}^*$  and the threshold value of the EPI  $y_S^*$  can be derived to specify the according compensation contract:

$$\bar{s}^* = 2\varepsilon(d + c_p\varepsilon) \text{ and } y_S^* = p_{max} - \frac{3\varepsilon}{2} - \frac{d}{2c_p}.$$

Thus, under a negligence regime, the bonus is higher and the threshold value is smaller, that is, more restrictive, than under strict liability. If the shareholders design the compensation contract in a way that managers realize a pollution level so that liability is ruled out for sure, they do not have to consider any liability payments. Their expected utility yields  $EU^s = -\bar{s} \cdot \left(\frac{y_S - p + \varepsilon}{2\varepsilon}\right)$  or, when inserting the bonus payment  $\bar{s}^*$ :

$$EU^s = -\frac{(d + c_p\varepsilon)^2}{2c_p}.$$

TABLE 4

RESULTS UNDER A NEGLIGENCE RULE, GIVEN THAT LIABILITY IS POSSIBLE:

$$\left( \text{Prob}(\tilde{y} > y_{opt}) > 0 \right)$$

Actual environmental pollution level	$p^* = \frac{2c_p^2 \epsilon p_{max} - d^2 - c_p d(\epsilon - p_{max})}{2c_p(d + c_p \epsilon)} < p_{opt}$
Bonus	$\bar{s}^* = \frac{\epsilon(d^2 + c_p d \epsilon + c_p d p_{max})}{c_p \epsilon + d} \geq 0$
Threshold value of EPI	$y_S^* = \frac{-d^2 + 4c_p^2 \epsilon(p_{max} - \epsilon) + c_p d(3p_{max} - 5\epsilon)}{4c_p(d + c_p \epsilon)}$
Expected utility of shareholders	$EU^s = \frac{d(d^3 + 2c_p d^2(\epsilon - p_{max}) - 4c_p^3 \epsilon^2 p_{max} + c_p^2 d(\epsilon^2 - 6\epsilon p_{max} + p_{max}^2))}{8c_p^2 \epsilon(d + c_p \epsilon)}$

The results are summarized in Table 3. Note first that the actual pollution  $p^*$  is lower than the socially optimal level and also lower than under strict liability and, second, that it *decreases* as the EPI becomes less precise (that is,  $\epsilon$  increases):

$$\frac{\partial p^*}{\partial \epsilon} = -1 < 0. \tag{18}$$

The more precise the EPI  $\tilde{y}$ , the less the manager needs to reduce the *actual* pollution level  $p$  in order to avoid negligence. Shareholders can pay a lower bonus and save managerial costs to incentivize actual pollution reductions then. Thus, shareholders' expected utility increases as the EPI becomes more precise (i.e.,  $\epsilon$  decreases):

$$\frac{\partial EU^s}{\partial \epsilon} = -d - c_p \epsilon < 0. \tag{19}$$

Shareholders achieve the highest expected utility for the most precise pollution report. Then,  $\epsilon = 0$  is valid and the actual pollution level equals the social optimum, that is,  $p^* = y_{opt}$ .

The EPI can indicate negligence ( $\text{Prob}(\tilde{y} > y_{opt}) > 0$ ) *Ex ante*, the probability that the EPI will exceed the standard of due care  $y_{opt}$  amounts to:

$$P(\tilde{y} > y_{opt}) = 1 - P(\tilde{y} \leq y_{opt}) = 1 - F(y_{opt}) = 1 - \frac{y_{opt} - (p - \epsilon)}{2\epsilon} \geq 0. \tag{20}$$

The expected utility of shareholders then reads:

$$EU^s = -\bar{s} \cdot \left( \frac{y_S - p + \epsilon}{2\epsilon} \right) - dp \left( 1 - \frac{p_{opt} - p + \epsilon}{2\epsilon} \right). \tag{21a}$$

Inserting the reaction function from equation (11) yields:



$$EU^s = -\bar{s} \cdot \left( \frac{y_S - p_{max} + \frac{\bar{s}}{2\epsilon c_p} + \epsilon}{2\epsilon} \right) - d \left( p_{max} - \frac{\bar{s}}{2\epsilon c_p} \right) \left( 1 - \frac{p_{opt} - p_{max} + \frac{\bar{s}}{2\epsilon c_p} + \epsilon}{2\epsilon} \right). \quad (21b)$$

Employing (13), the bonus  $\bar{s}^*$  and the threshold value of the EPI  $y_S^*$  can be determined. They are included in Table 4. The manager responds to the compensation contract conditions<sup>18</sup> with an actual pollution level that is lower than the social optimum and which now *increases* with the imprecision of the EPI:

$$p^* = \frac{2c_p^2 \epsilon p_{max} - d^2 - c_p d(\epsilon - p_{max})}{2c_p(d + c_p \epsilon)} < p_{opt} \quad \text{with} \quad \frac{\partial p^*}{\partial \epsilon} = \frac{c_p d p_{max}}{2(d + c_p \epsilon)^2} > 0.$$

Table 4 also depicts expected shareholder utility in equilibrium, which increases with a less imprecise EPI because

$$\frac{\partial EU^s}{\partial \epsilon} = - \frac{d^2(d^3 + 2c_p d^2(\epsilon - p_{max}) + 2c_p^3 \epsilon p_{max}(p_{max} - \epsilon) + c_p^2 d(\epsilon^2 - 4\epsilon p_{max} + p_{max}^2))}{8c_p^2 \epsilon^2 (d + c_p \epsilon)^2} \leq 0$$

holds for all  $p_{max} > 0$ ,  $d > 0$ ,  $p_{max} \cdot c_p > d$  and  $0 \leq \epsilon \leq p_{max} - \frac{d}{c_p}$ .

*The global optimum* The shareholders' expected utility is higher in the no-negligence case (i.e., just meeting the standard of due care) than in the negligence case ( $Prob(\tilde{y} > y_{opt}) > 0$ ) if it holds that:

$$EU^s_{liability\ ruled\ out} > EU^s_{liability\ possible} \Leftrightarrow$$

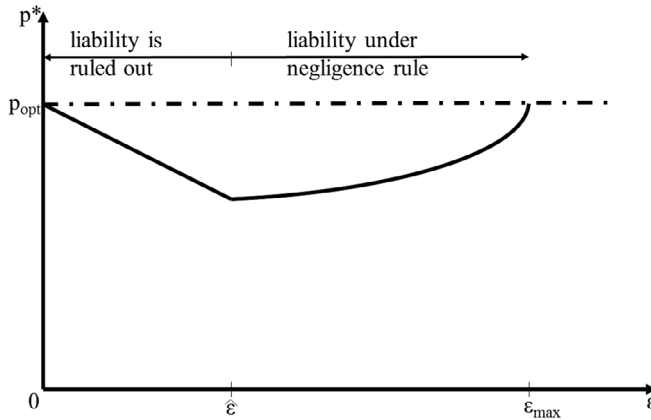
$$p_{max} - \frac{d}{c_p} > \frac{c_p \epsilon^2}{d + 2c_p \epsilon} + \sqrt{\frac{\epsilon^2 (d + c_p \epsilon)^2 (4d^3 + 20c_p^2 d \epsilon^2 + 8c_p^3 \epsilon^3 + c_p d^2 (1 + 16\epsilon))}{c_p d^2 (d + 2c_p \epsilon)^2}} \quad (22)$$

Since the right-hand side of the inequality in (22) monotonically increases in the imprecision of the EPI,  $\epsilon$ , but the left-hand side does not, there is a threshold level of imprecision,  $\hat{\epsilon}$ , above which shareholders will not want to meet the standard of due care. Ruling out liability becomes too costly then because the manager's bonus increases in the imprecision  $\epsilon$ . Thus, if  $\epsilon > \hat{\epsilon}$ , shareholders will set the threshold value of the EPI ( $y_S^*$ ) according to Table 4, albeit with a sufficient level of the indicator's precision ( $\epsilon \leq \hat{\epsilon}$ ), the threshold value is defined as in Table 3.

<sup>18</sup> The less precise the EPI (the higher  $\epsilon$ ), the higher the bonus needs to be:  $\frac{\partial \bar{s}^*}{\partial \epsilon} = \frac{d(d^2 + c_p^2 \epsilon^2 + c_p d(2\epsilon + p_{max}))}{(d + c_p \epsilon)^2} > 0$ .

FIGURE 2

ACTUAL POLLUTION LEVELS IN EQUILIBRIUM UNDER A NEGLIGENCE REGIME  
 DEPENDING ON EPI IMPRECISION,  $p^*(\epsilon)$



*Synthesis* Figure 2 illustrates the relationship between the EPI’s imprecision ( $\epsilon$ ) and the actual pollution level  $p^*$  in equilibrium. A first important and possibly surprising insight is that this relation is non-monotonic. As long as  $\epsilon$  does not exceed the threshold level  $\hat{\epsilon}$ , the manager chooses the actual pollution level  $p^*$  such that liability is ruled out and  $p^* + \epsilon = y_{opt}$  holds.<sup>19</sup> Thus, with a sufficiently low measurement error  $\epsilon$ , the actual pollution level  $p^*$  decreases in equilibrium. However, if the imprecision exceeds the threshold level  $\hat{\epsilon}$ , avoiding liability implies a compensation contract that becomes too expensive for the shareholders. They will set up an adjusted compensation scheme which changes the manager’s incentives. With increasing imprecision, the managers will not reduce the actual pollution level that much and so liability becomes possible.

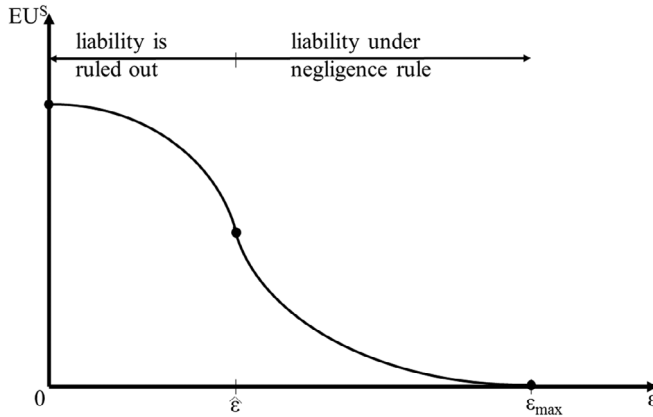
Note that the non-monotonic relation stands in contrast to the general claim in the literature that more noise in the EPI will negatively affect environmental performance (e.g., Virtanen *et al.*, 2013; Lisi, 2015).

The second important insight is that, due to the lack of the EPI’s precision, a negligence regime generally induces *lower* actual pollution levels than a strict liability rule—and lower than would be socially optimal. Thus, incentives of actual pollution reduction depend on the actual liability regime. Interestingly, those incentives are stronger under a negligence regime even though strict liability is

<sup>19</sup> This result stems from the assumption of a uniformly distributed EPI. With a normally distributed EPI, liability cannot be ruled out definitely. Still, I obtain similar qualitative results, because even when it is impossible to rule out liability definitely, it becomes very unlikely that the company will be held liable in the case of very precise measurement technology. See the Appendix for more details.

FIGURE 3

SHAREHOLDERS' EXPECTED UTILITY UNDER A NEGLIGENCE REGIME DEPENDING ON EPI MEASUREMENT ERROR,  $EU^S(\epsilon)$



thought to be more stringent. To the best of my knowledge, this finding is novel in the environmental performance measurement literature.

A third finding is that the shareholder's interest in the precision of the EPI depends on the liability regime. In contrast to a strict liability rule where shareholders' expected utility is independent of the EPI's precision, the company's shareholders have an interest in a higher precision of the EPI under a negligence regime. For sufficiently precise EPIs ( $\epsilon \leq \hat{\epsilon}$ ), when liability is ruled out definitely, as well as in the case where the EPI can indicate negligence ( $Prob(\hat{y} > y_{opt}) > 0$ ), which is the preferred strategy when  $\epsilon$  is too high ( $\epsilon > \hat{\epsilon}$ ), the shareholders' expected utility increases with a more precise EPI (i.e., a lower  $\epsilon$ ). Figure 3 illustrates this finding.

RESULT 2: (a) Under a negligence regime, the precision of the EPI matters. (b) Moreover, there is a non-monotonic relation between the precision of the EPI and the actual pollution level. (c) Shareholders benefit from a more precise measurement technology.

### MODEL EXTENSION: INCENTIVES FOR EPI MANIPULATION

In this section, the model is extended by a second managerial activity at  $t = 1$ , the manipulation of the EPI, indicated by  $i$ . Additional to the naturally given and in the short term not adaptable measurement imprecision, the managers can now bias the reported EPI deliberately. Think again of the Volkswagen example when a cheating software was implemented to downward bias the reported emissions

values. Transferred to a financial reporting context, EPI manipulation can be compared to earnings management.

The incentives for EPI manipulation are analyzed under strict liability as well as under negligence. I do not analyze the case of no liability, since there is no incentive to manipulate EPIs in that case.

*Manager's Manipulation Incentives Dependent on the Bonus*

Higher levels of manipulation tend to reduce the level of reported pollution:

$$E[\tilde{y}] = p - i. \tag{23}$$

I assume that  $i$  is unverifiable, with  $0 \leq i \leq p$ .<sup>20</sup> Contracts can still only be made based on the EPI  $\tilde{y}$ . Otherwise, there is symmetric information.

The probability that the manager will meet the threshold value of the EPI is defined by:

$$P(y \leq y_S) = \frac{y_S - p + i + \varepsilon}{2\varepsilon}. \tag{24}$$

Therefore, the shareholders' expected utility (see (7)) can be derived as:

$$EU^S = -\bar{s} \cdot \left( \frac{y_S - p + i + \varepsilon}{2\varepsilon} \right) - 0 \cdot \left( 1 - \frac{y_S - p + i + \varepsilon}{2\varepsilon} \right) - \text{expected environmental damage compensation}. \tag{25}$$

The manager's expected utility now also accounts for the disutility from EPI manipulation. In analogy to the task of pollution reduction, it is assumed to depend quadratically on the manager's particular effort. On the one hand it covers direct costs for measures that conceal the company's actual pollution level, for instance costs for the development and implementation of a cheating software in diesel engine control systems. On the other hand, this disutility can also include the manager's risk of being convicted of manipulation and the according punishment that they might fear.<sup>21</sup> Hence, a manager's expected utility function with EPI manipulation is:

$$EU^M = \bar{s} \cdot \left( \frac{y_S - p + i + \varepsilon}{2\varepsilon} \right) + 0 \cdot \left( 1 - \frac{y_S - p + i + \varepsilon}{2\varepsilon} \right) - \frac{1}{2}c_p(p_{max} - p)^2 - \frac{1}{2}c_i i^2. \tag{26}$$

The manager's incentive compatibility constraint with regard to actual pollution does not change compared with the basic analysis, that is,

<sup>20</sup> Consequently, I also adjust the assumption concerning the precision of the EPI:  $p - i \geq \varepsilon \geq 0$ .

<sup>21</sup> See the Appendix for an analysis of the impact of additional reputation loss due to manipulation.

TABLE 5

RESULTS WITH MANIPULATION OF POLLUTION REPORT UNDER STRICT LIABILITY

	No EPI manipulation	EPI manipulation
Shareholders' objective function	$EU^S = -\bar{s} \cdot \left(\frac{y_S - p + \varepsilon}{2\varepsilon}\right) - dp$	$EU^S = -\bar{s} \cdot \left(\frac{y_S - p + i + \varepsilon}{2\varepsilon}\right) - dp$
Actual pollution level	$p^* = P_{max} - \frac{d}{c_p} = p_{opt}$	$p^* = \frac{-c_i d + c_i c_p P_{max} + c_p^2 P_{max}}{c_p(c_i + c_p)} > p_{opt}$
Manipulation level	--	$i^* = \frac{d}{c_p + c_i}$
Bonus	$\bar{s}^* = 2d\varepsilon$	$\bar{s}^* = 2d\varepsilon \frac{c_i}{c_i + c_p}$
Threshold value of the EPI	$y_S^* = P_{max} - \varepsilon - \frac{d}{2c_p}$	$y_S^* = P_{max} - \varepsilon - \frac{d}{2c_p}$
Expected utility of shareholders	$EU^S = \frac{d(d - 2c_p P_{max})}{2c_p}$	$EU^S = \frac{d(-2c_p^2 P_{max} + c_i(d - 2c_p P_{max}))}{2c_p(c_i + c_p)}$

$\frac{\partial EU^M}{\partial p} = \frac{-\bar{s}}{2\varepsilon} + c_p(p_{max} - p) = 0$  (see (10)). Consequently, the manager's reaction function (actual pollution level  $p$  depending on bonus  $\bar{s}$ ) does not change either (see(11)):

$$p(\bar{s}) = P_{max} - \frac{\bar{s}}{2\varepsilon c_p}. \tag{27}$$

With EPI manipulation, a second incentive compatibility constraint has to be considered:

$$\frac{\partial EU^M}{\partial i} = \frac{\bar{s}}{2\varepsilon} - ic_i = 0. \tag{28}$$

The manager's manipulation reaction function then reads:

$$i(\bar{s}) = \frac{\bar{s}}{2\varepsilon c_i}. \tag{29}$$

Thus, the more precise the EPI (the lower  $\varepsilon$  is), the stronger the incentives for EPI manipulation. Considering the manager's zero reservation utility and the reaction functions  $p(\bar{s})$  and  $i(\bar{s})$ , the threshold value for the pollution indicator ( $y_S$ ) can be determined:

$$y_S(\bar{s}) = P_{max} - \varepsilon - \frac{(c_p + c_i)\bar{s}}{4\varepsilon c_p c_i} \tag{30}$$

*Manipulation of Reported Pollution under Strict Liability*

Table 5 summarizes the results for the cases with and without EPI manipulation under a strict liability regime.

The corresponding threshold value for the EPI is the same as it is without the possibility of EPI manipulation. Inserting the reaction function and setting the first partial derivative with respect to  $\bar{s}$  zero leads to a bonus that is lower than without manipulation because  $\frac{c_i}{c_p + c_i} < 1$ . This is not too surprising since shareholders will rationally anticipate that the manager is able to manipulate the EPI and, thus, lower the reward tied to the manipulated performance indicator (Beyer and Guttman, 2012). The manipulation level in equilibrium is positive,  $i^* = d/(c_p + c_i)$ . Manipulation pays off more as damage payments increase, and decreases with cost parameters  $c_p$  and  $c_i$ . Since the manager manipulates the reported pollution level  $\tilde{y}$ , they are able to raise the *actual* pollution level accordingly. Thus, actual pollution is higher than in the initial strict liability model and, thus, higher than the socially optimal level. Recall that actual pollution and EPI manipulation are not verifiable such that shareholders are unable to contract on either managerial activity. *Ex post*, the manager will rationally manipulate the pollution report. In order to meet the manager's participation constraints *ex ante*, shareholders need to take into account the manager's manipulation costs. Compared with the model without manipulation, shareholders' expected utility is *reduced*:<sup>22</sup> shareholders anticipate that the company's actual pollution  $p^*$  will be higher than without manipulation, which results in higher future damage compensation.

*Manipulation of Reported Pollution and Actual Pollution under a Negligence Regime*

Compared with the case of strict liability, only shareholders' expected damages and, thus, shareholders' expected utility will be different under a negligence regime. 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 two different scenarios: (a) when there is no manipulation of the pollution report, and (b) when there is manipulation. Table 6 also distinguishes between the two different strategies of avoiding any possibility of liability ( $Prob(\tilde{y} \leq y_{opt}) = 1$ ) or accepting the possibility of liability ( $Prob(\tilde{y} > y_{opt}) > 0$ ).

If shareholders want to rule out any possibility of being held liable, they will set up a compensation contract that induces a pollution level with  $p - i + \varepsilon \leq y_{opt}$ . Thus, compared with the basic analysis, the possibility to manipulate pollution reports will induce the manager to increase actual pollution without the EPI indicating a violation of the standard of due care.

Similar to the strict liability case there is EPI manipulation ( $i^*$  is greater than zero) and, as a consequence, actual pollution levels will be higher than without manipulation. In the absence of EPI manipulation, a negligence regime induces lower than socially optimal actual pollution, but in the case of manipulation, actual pollution may even exceed the social optimum. What differs from strict liability is

<sup>22</sup>  $EU_{i=0}^S = \frac{d(d-2c_p p_{max})}{2c_p} > EU_{i=i^*}^S = \frac{d(-2c_p^2 p_{max} + c_i(d-2c_p p_{max}))}{2c_p(c_i + c_p)}$  for all  $d, c_p, c_i, p_{max} > 0$ .

TABLE 6  
RESULTS WITH MANIPULATION OF POLLUTION REPORT UNDER NEGLIGENCE REGIME

	Liability is ruled out: $Prob(\tilde{y} \leq y_{opt}) = 1$	Liability is possible: $Prob(\tilde{y} > y_{opt}) > 0$
	No EPI manipulation	EPI manipulation
	No EPI manipulation	No EPI manipulation
	EPI manipulation	EPI manipulation
Shareholders' objective function $EU^s$	$-\bar{s} \cdot \left( \frac{y_s - p + i + \epsilon}{2\epsilon} \right)$	$-\bar{s} \cdot \left( \frac{y_s - p + i + \epsilon}{2\epsilon} \right) - dp \left( 1 - \frac{p_{max} - p + i + \epsilon}{2\epsilon} \right)$
Actual pollution level $p^*$	$p_{max} - \frac{d}{c_p} - \epsilon < p_{opt}$	$\frac{d(c_p^2 p_{max} + c_i(d + c_p)(\epsilon + p_{max}))}{2c_p \epsilon p_{max}} - \frac{2c_p \epsilon p_{max}}{(c_i + c_p)(d + c_p \epsilon)}$
Manipulation level $t^*$	--	$\frac{d + c_p \epsilon}{c_i + c_p}$
Bonus $\bar{s}^*$	$2\epsilon(d + c_p \epsilon)$	$\frac{\epsilon(d^2 + c_p d \epsilon + c_p d p_{max})}{c_p \epsilon + d}$
Threshold value of EPI $y_s^*$	$p_{max} - \frac{3\epsilon}{2} - \frac{d}{2c_p}$ + $\frac{c_p d(3p_{max} - 5\epsilon)}{4c_p(d + c_p \epsilon)}$ + $\frac{c_p d(3p_{max} - 5\epsilon)}{4c_p(d + c_p \epsilon)}$	$\frac{\epsilon(c_i d^2 + c_i c_p d \epsilon + c_i c_p d p_{max} + c_p^2 d p_{max})}{(c_i + c_p)(d + c_p \epsilon)} \geq 0$ $p_{max} - \epsilon - \frac{d(c_p^2 p_{max} + c_i(d + c_p)(\epsilon + p_{max}))}{4c_i c_p(d + c_p \epsilon)} \geq 0$
Expected utility of shareholders	$-\frac{(d + c_p \epsilon)^2}{2c_p}$ + $\frac{d(\beta^2 + 2c_p \beta^2(\epsilon - p_{max}) - 4c_p^3 \epsilon^2 p_{max})}{8c_p^2 \epsilon(d + c_p \epsilon)}$ + $\frac{d(c_p^2 d(\epsilon^2 - 6\epsilon p_{max} + p_{max}^2))}{8c_p^2 \epsilon(d + c_p \epsilon)}$	$\frac{d(-2c_p^2(d^2 + 2c_p^2 \epsilon^2 + c_p d(3\epsilon - p_{max}))p_{max} + c_p^4 d p_{max}^2)}{8c_i c_p^2(c_i + c_p)\epsilon(d + c_p \epsilon)}$ + $\frac{d(c_i^2(\beta^2 + 2c_p \beta^2(\epsilon - p_{max}) - 4c_p^3 \epsilon^2 p_{max}))}{8c_i c_p^2(c_i + c_p)\epsilon(d + c_p \epsilon)}$ + $\frac{c_p^2 d(\epsilon^2 - 6\epsilon p_{max} + p_{max}^2)}{8c_i c_p^2(c_i + c_p)\epsilon(d + c_p \epsilon)}$

that shareholders clearly *benefit* from pollution report manipulation. Since the EPI is the only verifiable measure of actual pollution, manipulation of the EPI reduces the probability of being held liable. For  $p_{max}, \varepsilon, d, c_p, c_i > 0$  and  $\varepsilon \leq p_{opt}$ , which is ensured by definition, shareholders' expected utility increases compared with the model without manipulation in both cases, when liability is ruled out ( $Prob(\tilde{y} \leq y_{opt}) = 1$ ) as well as when liability is possible ( $Prob(\tilde{y} > y_{opt}) > 0$ ). In this way, shareholders benefit from pollution report manipulation under a negligence regime and higher manipulation levels than under strict liability are realized.

RESULT 3: (a) *If the manager is able to manipulate the EPI, they will do so, which in turn increases actual pollution and future environmental damages.* (b) *Under strict liability, the company's shareholders are fully responsible for damages, and thus they are worse off when pollution report manipulation is possible.* (c) *In contrast, under a negligence regime, the company's shareholders benefit from EPI manipulation, since this reduces the likelihood of being held negligent and hence the expected damage compensation payments.* (d) *The non-monotonic relation between measurement precision and actual pollution levels in the negligence regime also remains when environmental reports can be manipulated.*<sup>23</sup>

I find a negative association between EPI manipulation and environmental performance, which is consistent with Clarkson *et al.*'s (2008) empirical findings and matches anecdotal evidence such as in the case of the Volkswagen diesel scandal. Still, while the theoretical foundation in Clarkson *et al.* (2008) refers to an information argument as presented in Li *et al.* (1997), specifically self-selection effects, the main drivers in my model are the liability regime and moral hazard due to a separation of ownership and control.

## CONCLUSION

In this paper, I analyzed how the environmental liability regime affects managers' incentives (1) to reduce *actual* pollution and (2) to report the environmental pollution level truthfully, given that reported information can be used in litigation, manipulation is not verifiable, and that there is a separation of ownership and control. Actual pollution levels are not verifiable, but are measured by a verifiable, albeit imprecise, environmental performance indicator. I find that a negligence regime implies lower actual pollution levels than strict liability in the *absence* of EPI manipulation. This is because, under a negligence regime, shareholders have the chance to escape liability if they induce managers to realize sufficiently low pollution levels. This is not possible under strict liability. However, if EPI manipulation is possible, a negligence regime provides stronger incentives for manipulation than a strict liability regime: shareholders suffer from pollution report manipulation with strict liability since expected damage compensation then increases. In contrast, under

<sup>23</sup> This can be inferred from Table 6,  $\frac{\partial p^*}{\partial \varepsilon} < 0$  if liability is ruled out and  $\frac{\partial p^*}{\partial \varepsilon} > 0$  if liability is possible.



a negligence rule, EPI manipulation decreases the likelihood of being held negligent and, thus, shareholders benefit from this manipulation.

To the best of my knowledge, the assignment of the environmental liability regime in the EU and the US is not related to a company's characteristics, such as whether there is a separation of ownership and control, and the extent to which there are opportunities for EPI manipulation. My model suggests that a 'one size fits all' approach would be unsuitable to properly address the specific incentives caused by these characteristics. Moreover, policymakers' concrete objectives are relevant. If an efficient pollution level is the aim, and reliable verification processes allow for virtually no pollution report manipulation, then a strict liability regime should be set up. If policymakers want to achieve the lowest possible pollution level and if pollution report manipulation can be excluded then a negligence regime should be introduced, but an improvement of the state-of-the-art measurement technology might lead to higher pollution levels. If it is possible for managers to considerably manipulate the pollution report, then the regulator should install a strict liability regime because in that case shareholders will not support the manager's incentives for manipulation. Additional analyses suggest that a sufficient reputation loss imposed on the company and, therefore, its shareholders, reduces potential shareholders' benefits from manipulation. Hence, a blacklist of manipulating companies could support regulators' efforts to reduce EPI manipulation.

To test the robustness of these results, several robustness checks were performed. Introducing a second managerial task, analyzing an alternative form of the compensation contract, and assuming a normally distributed EPI address seemingly crucial basic assumptions of the main model and show that the results are robust even if these assumptions are altered. Extending the model by reputation losses either due to high EPI values or EPI manipulation lead to intuitively comprehensible shifts of the equilibria while supporting the main insights obtained with the basic model structure.

A number of predictions for empirical research for companies with a separation of ownership and control can be drawn from this model. I expect that a shift from a negligence regime in environmental liability to a strict liability regime will reduce the extent of EPI manipulation. Within a negligence regime, I would expect a major improvement in pollution measurement to *increase* pollution levels if it is relatively easy to meet the standard of due care. Finally, within a strict liability regime, I expect companies with a separation of ownership and control to exhibit higher levels of pollution report manipulation than companies with manager-owners.

Moreover, the results have implications for (empirical) cross-country environmental accounting research in general. Given the differential impacts of the liability regime on companies' environmental reporting and actual pollution decisions, it is necessary to control for the liability regime when comparing environmental reporting and environmental performance in different countries with different liability regimes. Prior results from cross-country comparisons may need to be checked whether they still hold when the impact of the liability regime is incorporated in regression

analyses. Future (empirical) environmental accounting studies can provide evidence on the magnitude of the liability regime's impact on managerial reporting choices and corporate real decisions.

A few limitations need to be mentioned. I did not analyze the impact of the manager's personal liability nor explicitly allow for the manager's capacity constraints. However, basic analysis suggests that the qualitative results will not change much. Further, I implicitly assumed that the EPI is the only information source for courts to evaluate negligence. In reality, courts will also try to find other evidence on managerial behaviour. Nevertheless, with truthful reporting it is likely that pollution levels measured by a court are highly correlated if not identical with a company's reported EPI if they have to rely on similar measurement technology. Finally, I assume that victims do not bear transaction costs when bringing lawsuits, while in fact these costs are positive. This would add a third player, requiring a game-theoretical extension.

### LIST OF SYMBOLS

Latin symbol	Meaning
$b$ ( $b^*$ )	Manager's effort for 'business as usual' task, $0 \leq b$ (equilibrium solution)
$c_b$	Disutility parameter, expressing (manager's) cost for 'business as usual' task, $c_b > 0$
$c_i$	Disutility parameter, expressing (manager's) cost for EPI manipulation, $c_i > 0$
$c_p$	Disutility parameter, expressing (manager's) cost of reducing environmental pollution, $c_p > 0$
$d$	Marginal environmental damage, $D/p_{max}$
$D$	Maximum monetarily quantifiable environmental damage, caused by a certain company's pollution
$E$	Expected value operator
$EC$	Expected costs for whole society
erf	Error function
erfc	Complementary error function
$F$	Distribution function of normal distribution
$i$ ( $i^*$ )	Manager's effort for EPI manipulation, $0 \leq i \leq p$ (equilibrium solution)
$M$	Manager
$N$	Normal distribution operator
$p$ ( $p^*$ )	Company's actual environmental pollution level, $0 \leq p \leq p_{max}$ , (equilibrium solution)

$p_{max}$	Company's maximum environmental pollution level
$p_{opt}$	Socially optimal environmental pollution level
$P$	Probability operator
$r_i^M (R_i^M)$	Manager's incremental (maximum) reputation loss due to EPI manipulation, $r_i^M, R_i^M > 0$
$r_i^S (R_i^S)$	Shareholder's incremental (maximum) reputation loss due to EPI manipulation, $r_i^S, R_i^S > 0$
$r_{EPI} (R_{EPI})$	Manager's incremental (maximum) reputation loss due to high values of EPI manipulation, $r_{EPI}, R_{EPI} > 0$
$S$	Shareholder
$s(\tilde{y})$	Bonus contract the shareholder offers to the manager, dependent on the EPI
$s(\tilde{x}, \tilde{y})$	Bonus contract the shareholder offers to the manager, dependent on the FPI and the EPI simultaneously
$\bar{s} (\bar{s}^*)$	Bonus the manager can receive (equilibrium solution)
$\bar{s}_x, \bar{s}_y (\bar{s}_x^*, \bar{s}_y^*)$	Bonus the manager can receive dependent on the realizations of the FPI or the EPI, respectively (equilibrium solution)
$t$	Time variable
$T$	Point in time when environmental damage occurs and liability is realized
$U^M (EU^M)$	(Expected) utility of the manager
$U^S (EU^S)$	(Expected) utility of the shareholders
$\tilde{x}$	FPI, stochastic variable
$x$	Realization of $\tilde{x}$
$x_S (x_S^*)$	Threshold value for receiving a bonus due to favourable realizations of $\tilde{x}$ , set by the shareholders (equilibrium solution)
$\tilde{y}$	EPI, stochastic variable
$y$	Realization of $\tilde{y}$
$y_{opt}$	Standard of due care (with respect to company's environmental pollution)
$y_S (y_S^*)$	Threshold value for receiving a bonus due to favourable realizations of $\tilde{y}$ , set by the shareholders (equilibrium solution)
Greek symbol	Meaning
$\alpha$	Parameter of the linear compensation contract (fixed part)
$\beta$	Parameter of the linear compensation contract, specifies the impact of the EPI on salary
$\partial$	Partial derivative operator
$\varepsilon$	Distribution parameter of $\tilde{y}, 0 \leq \varepsilon \leq p_{opt}$ , reflects the (lack of) precision of the EPI
$\hat{\varepsilon}$	Threshold level of imprecision (above which shareholders will not want to meet the standard of due care)
$\pi$	Distribution parameter of $\tilde{x}, 0 \leq \pi \leq b$
$\phi$	Standardized distribution function of normal distribution

APPENDIX:

To test the robustness of Results 1, 2, and 3, several robustness checks were performed. Introducing a second managerial task, analyzing an alternative form of the compensation contract, and assuming a normally distributed EPI address seemingly crucial basic assumptions of the main model and show that the results are robust even if these assumptions are altered. Extending the model by reputation losses either due to high EPI values or EPI manipulation leads to intuitively comprehensible shifts of the equilibria while supporting the main insights obtained with the basic model structure.

*Second Managerial Task*

The main analysis focuses on managers' efforts to reduce companies' environmental pollution. Since it is not the aim of this paper to develop a model for effort sharing and optimal compensation contracts for a multitasking manager, as, for example, Feltham and Xie (1994) do, it has been omitted that managers will naturally have to perform more tasks than just this environmentally related one. Nevertheless, for the sake of a more realistic model, a 'business as usual' task,  $b$ , can be introduced as a robustness check. Higher managerial effort for this task leads to a higher financial performance, for example, higher profits or higher revenues. The corresponding financial performance indicator (FPI) is denoted as  $\tilde{x}$  and assumed to be uniformly distributed:  $\tilde{x} \sim \text{uniform}(b - \pi, b + \pi)$ , with  $0 \leq \pi \leq b$  and an expected value  $E[\tilde{x}] = b$ . To keep the analysis simple,<sup>24</sup> it is assumed that each effort only affects its particular performance indicator. If a certain financial threshold  $x_S$  is exceeded, the manager receives a(n) (additional) bonus  $\bar{s}_x$ . Thus, the adjusted compensation scheme is:

$$s(\tilde{x}, \tilde{y}) = \begin{cases} \bar{s}_x + \bar{s}_y & \text{if } \tilde{x} \geq x_S \text{ and } y \leq y_S \\ \bar{s}_y & \text{if } \tilde{x} < x_S \text{ and } y \leq y_S \\ \bar{s}_x & \text{if } \tilde{x} \geq x_S \text{ and } y > y_S \\ 0 & \text{if } \tilde{x} < x_S \text{ and } y > y_S \end{cases} \quad \text{with } \bar{s}_x, \bar{s}_y \geq 0. \quad (\text{A1.1})$$

The shareholder's expected utility function is adjusted by this compensation scheme. Additionally, a good financial performance benefits the shareholders. Thus, shareholder's expected utility function is the expected financial performance

<sup>24</sup> There is evidence that a company's environmental and financial performance are related but there are arguments and evidence for both directions of this relation. While Guenster *et al.* (2011) and Qian and Xing (2016) find a positive association between environmental and financial performance, the results of Horváthová (2012) as well as Delmas *et al.* (2015) support a negative association at least in the short run. Trumpp and Guenther (2017) find a U-shaped relationship. Incorporating all possible realizations of the link between environmental and financial performance would result in several case discriminations. I refrain from introducing such a link because it would shift attention away from the initial research question. Basic analyses show that the important main results also hold when the two performances are linearly linked and both influence the FPI. Nevertheless, a comprehensive analysis of this scenario might be an interesting issue for further research.

minus the expected salary for the manager and minus expected environmental damage compensation payments, depending on the environmental liability regime:

$$EU^s = b - \bar{s}_x \cdot \left(1 - \frac{x_S - b + \pi}{2\pi}\right) - 0 \cdot \left(\frac{x_S - b + \pi}{2\pi}\right) - \bar{s}_y \cdot \left(\frac{y_S - p + \varepsilon}{2\varepsilon}\right) - 0 \cdot \left(1 - \frac{y_S - p + \varepsilon}{2\varepsilon}\right) - \text{exp.env.damage compensation.} \quad (\text{A1.2})$$

Hence, a positive expected shareholder utility is possible. Managers' expected utility function is expanded by the disutility from performing the 'business as usual' task and reads as:

$$EU^M = \bar{s}_x \cdot \left(1 - \frac{x_S - b + \pi}{2\pi}\right) + 0 \cdot \left(\frac{x_S - b + \pi}{2\pi}\right) + \bar{s}_y \cdot \left(\frac{y_S - p + \varepsilon}{2\varepsilon}\right) + 0 \cdot \left(1 - \frac{y_S - p + \varepsilon}{2\varepsilon}\right) - \frac{1}{2}c_b \cdot b^2 - \frac{1}{2}c_p(p_{max} - p)^2. \quad (\text{A1.3})$$

Analogous to the basic model, this model can be solved with backwards induction. Manager's incentive compatibility constraints result in the reaction functions  $b(\bar{s}_x) = \frac{\bar{s}_x}{2c_b\pi}$  and  $p(\bar{s}_y) = p_{max} - \frac{\bar{s}_y}{2c_p\varepsilon}$ . Since the value of the FPI is only affected by the manager's effort for the 'business as usual task' and not by the pollution level or the environmental liability regime, the bonus  $\bar{s}_x = 2\pi$  as well as the equilibrium effort level  $b^* = \frac{1}{c_b}$  are the same for all analyzed scenarios (no liability, strict liability, negligence, EPI manipulation under both liability regimes). Given the independence of both tasks, the bonus for environmental performance  $\bar{s}_y$  and the pollution level in equilibrium  $p^*$  are also unaffected by the introduction of this second task. Thus, all results obtained in the basic model remain unchanged and are robust.

Only the determination of the threshold values  $(x_S, y_S)$  is not straightforward in this model. Inserting the reaction functions  $b(\bar{s}_x)$  and  $p(\bar{s}_y)$  into managers' participation constraint shows that there are different combinations of thresholds  $(x_S, y_S)$  that ensure that the manager's reservation utility of zero is met. For instance, under strict liability the thresholds for getting a bonus have to fulfil the following equation to meet managers' participation constraint:

$$0 = \frac{1}{2c_b} + \frac{d^2}{2c_p\varepsilon} + d\varepsilon + \pi - dp_{max} - x_S + dy_S. \quad (\text{A1.4})$$

The higher the threshold for getting the bonus for financial performance  $x_S$ , the easier it is to achieve the threshold for the environmental performance related bonus, and vice versa.

*Linear Compensation Contract*

The simple hurdle rate contract that is applied in the main model permits a first best solution (Holmström, 1979). It is explicitly not the aim of this paper to develop an optimal compensation contract. Still, questions concerning the sensitivity of the results with other compensation contracts are valid. Anecdotal evidence suggests that EPIs—if applied in managers’ compensation schemes—are part of a variable component (e.g., Lufthansa Group Annual Report, 2017; BMW Group Annual Report, 2017). Transforming this into a mathematical expression suggests the application of a linear compensation contract:

$$s(\tilde{y}) = \alpha + \beta\tilde{y} \tag{A2.1}$$

where  $\alpha$  is a fixed compensation parameter and  $\beta$  represents the dependence of the manager’s compensation on the EPI  $\tilde{y}$ .

Lagrange optimization of the shareholder’s expected utility in the different scenarios with respect to the manager’s binding incentive compatibility ( $\frac{\partial EU^M}{\partial p} = 0$ ) and participation constraint ( $EU^M = 0$ ) results in the same findings as obtained in the basic model: *RESULTS 1 (a) and (b)*, *RESULTS 2 (a), (b), and (c)* as well as *RESULTS 3 (a), (b), (c), and (d)* are robust with respect to the application of a linear compensation contract.

*Normally Distributed EPI*

The assumption of a uniformly distributed environmental performance indicator  $\tilde{y}$  allows closed-form model solutions. I now assume this indicator to be normally distributed:

$$\tilde{y} \sim N(p, \varepsilon) \tag{A3.1}$$

The analysis and results of the no-liability case, the socially optimal pollution level, and the case of strict liability with and without manipulation do not change because  $E[\tilde{y}] = p$  (or  $E[\tilde{y}] = p - i$ , respectively) still holds in analogy to a uniformly distributed EPI. For all of these cases, only the expected value of the EPI matters. Therefore, only the results under a negligence rule have to be reconsidered.

With a normally distributed EPI, the probability of being held liable for environmental damage reads:

$$Prob(\tilde{y} > y_{opt}) = 1 - F\left(y_{opt} = p_{max} - \frac{d}{c_e}\right) = 1 - \phi\left(\frac{p_{max} - \frac{d}{c_e} - p}{\varepsilon}\right). \tag{A3.2}$$

The probability that the manager will receive the bonus is:

$$Prob(\tilde{y} < y_s) = F(y_s) = \phi\left(\frac{y_s - p}{\varepsilon}\right). \tag{A3.3}$$

Therefore, the manager's expected utility is reflected by:

$$EU^M = \bar{s} \cdot \phi\left(\frac{y_s - p}{\varepsilon}\right) - \frac{1}{2}c_p(p_{max} - p)^2 \tag{A3.4}$$

Shareholders' expected utility reads:

$$EU^S = -\bar{s} \cdot \phi\left(\frac{y_s - p}{\varepsilon}\right) - dp \cdot \left(1 - \phi\left(\frac{p_{max} - \frac{d}{c_p} - p}{\varepsilon}\right)\right). \tag{A3.5}$$

The participation constraint again sets a lower bound for the manager's expected utility:

$$EU^M = \bar{s} \cdot \phi\left(\frac{y_s - p}{\varepsilon}\right) - \frac{1}{2}c_p(p_{max} - p)^2 \geq 0. \tag{A3.6a}$$

$$\text{or } EU^M = \bar{s} \cdot \frac{1}{2} \left(1 + \operatorname{erf}\left(\frac{y_s - p}{\sqrt{2}\varepsilon}\right)\right) - \frac{1}{2}c_p(p_{max} - p)^2 \geq 0, \text{ respectively.}^{25} \tag{A3.6b}$$

In equilibrium, this inequality is binding and holds as an equality. Taking this into account and generating the first partial derivative of the manager's expected utility with respect to the pollution level,  $p$ , reveals an implicit condition for the link between individual optimal pollution levels,  $p^*$ , and possible bonus payments,  $\bar{s}$ , in equilibrium:

$$c_p(p_{max} - p^*) - \frac{e^{-\operatorname{erfc}^{-1}\left[\frac{c(p_{max} - p^*)^2}{\bar{s}}\right]^2}}{\varepsilon\sqrt{2\pi}} = 0. \tag{A3.7}$$

Inserting (A 3.6a) into (A 3.5) leads to the principal's expected utility, which depends on the imprecision,  $\varepsilon$ , and on the pollution level in equilibrium,  $p^*$ :

$$EU^S(p^*(\varepsilon), \varepsilon) = -\frac{c_p}{2}(p^* - p_{max})^2 - dp^* \frac{1}{2} \operatorname{erfc}\left[\frac{p_{max} - \frac{d}{c_p} - p^*}{\sqrt{2}\varepsilon}\right]. \tag{A3.8}$$

Calculating the first partial derivative of (A 3.8) with respect to the pollution level,  $p^*$ , leads to an implicit condition that reveals the pollution level induced by the shareholders (by setting the corresponding bonus that can be determined with (A 3.7):

<sup>25</sup> With the error function being described by  $\phi\left(\frac{y_s - p}{\varepsilon}\right) = \frac{1}{2} \left(1 + \operatorname{erf}\left(\frac{y_s - p}{\sqrt{2}\varepsilon}\right)\right)$ .

<sup>26</sup> With the complementary error function  $\operatorname{erfc}(x)$  being defined as  $\operatorname{erfc}(x) = 1 + \operatorname{erf}(x)$  and the inverse complementary error function  $\operatorname{erfc}^{-1}(z)$  being defined by  $\operatorname{erfc}^{-1}(1 - z) = \operatorname{erf}^{-1}(z)$ .

$$-\frac{d\epsilon}{\epsilon\sqrt{2\pi}} \frac{(d+c_p p - c_p p_{max})^2}{2c_p^2 \epsilon^2} p + c_p(p_{max} - p^*) - d \frac{1}{2} \operatorname{erfc} \left[ \frac{p_{max} - p^* - \frac{d}{c_p}}{\sqrt{2}\epsilon} \right] = 0. \tag{A3.9}$$

This system of equations cannot be solved analytically because of the complementary error function, which stems from the normal distribution. In principle, a numerical solution with exemplary values for distinct parameters provides insights into the curve progression. Assume  $c_p = 2$ ,  $d = 4$ , and  $p_{max} = 5$ . The individual optimal pollution level in equilibrium depending on the measurement precision can be gathered from Figure 4.

Similar to the model with a uniformly distributed EPI, the manager reduces pollution levels below the social optimum, given that the precision of the EPI is not too low (too high  $\epsilon$ ). With a normally distributed EPI, there is a special feature for low levels of precision: if  $\epsilon$  becomes too high, companies will consider the corresponding EPI  $\tilde{y}$  to be largely uninformative and thus inadequate for preventing 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. 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 shareholders' expected utility for high values of  $\epsilon$ , which stems from savings from decreased pollution-reduction activities. Nevertheless, even for the most imprecise measurement technology, that is,  $\epsilon = p_{max} - \left(\frac{d}{c_p}\right)$ , and the highest possible pollution level, that is,  $p = p_{max}$ , shareholders' expected utility will always be lower than for the most precise measurement technology, that is,  $\epsilon \rightarrow 0$ . Thus, the finding that shareholders would benefit from a more precise measurement technology (which I derived with a uniformly distributed parameter) also holds with normally distributed EPIs.

To obtain the results for pollution report manipulation under a negligence regime, once again, only the probability of exceeding the due diligence

FIGURE 4

POLLUTION LEVELS WITH UNIFORMLY AND NORMALLY DISTRIBUTED EPIs

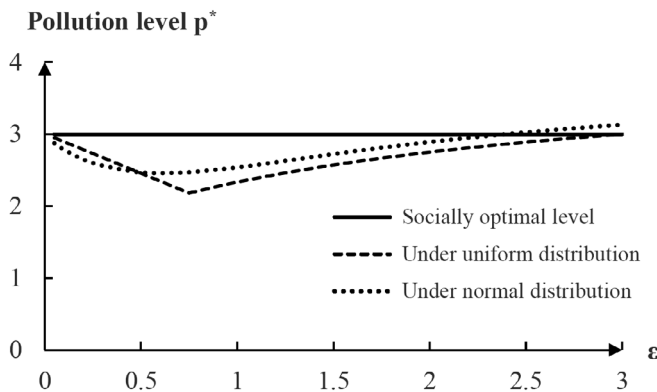
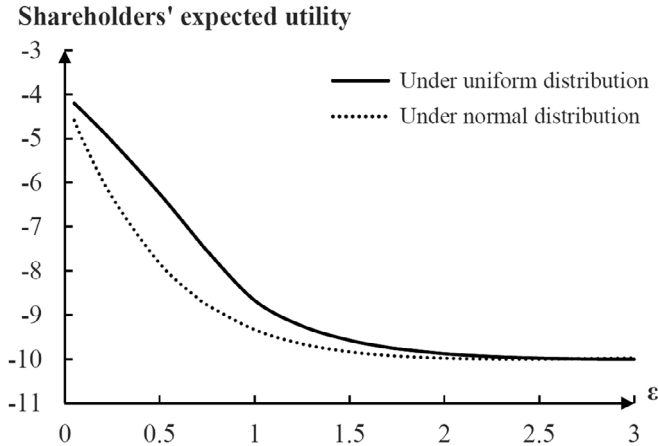




FIGURE 5

SHAREHOLDERS' EXPECTED UTILITY WITH UNIFORMLY OR NORMALLY DISTRIBUTED EPIS



threshold,  $y_{opt}$  (A 3.2), and the probability of complying with the shareholders' threshold value,  $y_s$  (A 3.3), has to be adjusted. Figure 6 depicts the pollution level depending on the EPI's imprecision for the different cases.

The basic results remain unchanged: when the manager is able to manipulate the reports, they will do so, yielding higher actual pollution levels. Nevertheless, shareholders benefit from the manager's manipulation of reports, because it

FIGURE 6

POLLUTION LEVEL UNDER A NEGLIGENCE REGIME WITH NORMALLY DISTRIBUTED EPI

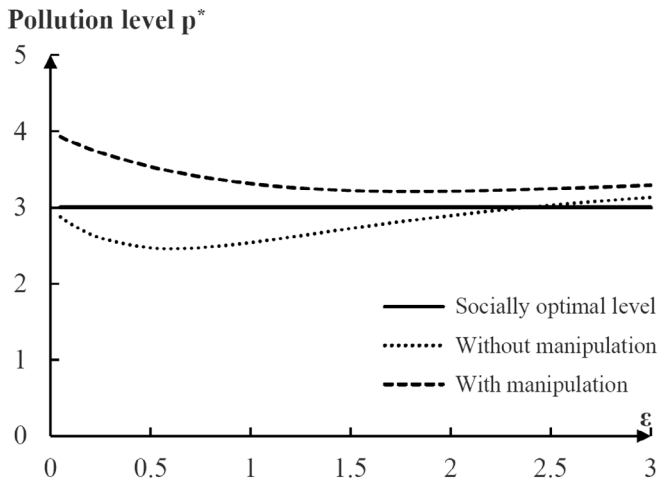
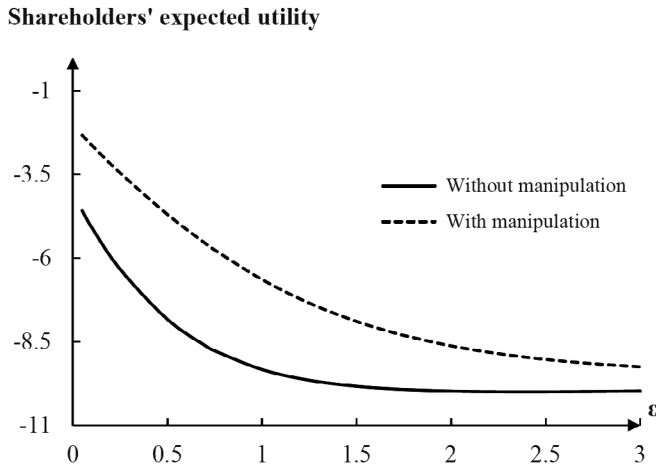


FIGURE 7

SHAREHOLDERS' EXPECTED UTILITY DEPENDENT ON EPI'S IMPRECISION UNDER NEGLIGENCE REGIME WITH NORMALLY DISTRIBUTED EPI



reduces their likelihood of being held liable for environmental pollution. Figure 7 illustrates this effect (dashed line).

*Manager's Reputation Loss Due to High EPI Values*

I extend the basic model by introducing a reputation loss that affects the manager due to the reported environmental pollution level. In recent years, companies' environmental performance has become increasingly important to investors and academics (e.g., Perez-Batres *et al.*, 2012; Cormier and Magnan, 2015; Guenther *et al.*, 2016). There is evidence that financial markets punish bad environmental performance with lower share prices (e.g., Matsumura *et al.*, 2014; Griffin *et al.*, 2017), and that environmental issues in general are included in a company's risk assessment (e.g., Kim *et al.*, 2015; Jung *et al.*, 2018). Therefore, managers who are responsible for a company's environmental performance might be held accountable directly or indirectly if they report high pollution levels. Stakeholders as creditors or suppliers could link this specific manager with a non-sustainable and, therefore, unfavourable company development. Also shareholders could lose their trust in a seemingly not environmentally conscious manager. Thus, managers might suffer a reputation loss for high reported EPI values. In a broad sense, a manager's personal liability towards the shareholders can also be modelled as such a reputation loss.

Hence, I expand the manager's expected utility function as represented in (9) by the expected value of the EPI multiplied by an incremental reputation loss<sup>27</sup>,  $r_{EPI}$ .

<sup>27</sup> The incremental reputation loss,  $r_{EPI}$ , is the maximum reputation loss,  $R_{EPI}$ , normalized by the maximum pollution level  $p_{max}$ . A reputation loss of  $r_{EPI} \cdot p$  ensures that if the pollution is maximal, the reputation loss is maximal as well; if it is zero, then no reputation loss is expected.

$$EU^M = \bar{s} \cdot \left( \frac{y_S - p + \varepsilon}{2\varepsilon} \right) + 0 \cdot \left( 1 - \frac{y_S - p + \varepsilon}{2\varepsilon} \right) - \frac{1}{2} c_p (p_{max} - p)^2 - r_{EPI} \cdot p. \quad (A4.1)$$

Solving the adjusted model with backwards induction results in reaction functions that include reputation loss. For instance, the pollution level depending on the bonus,  $p(\bar{s}) = p_{max} - \frac{r_{EPI}}{c_p} - \frac{\bar{s}}{2\varepsilon c_p}$ , decreases with a higher reputation loss. Interpreting reputation loss as an additional cost imposed on the manager, it also enters the expected cost function of the whole society and the socially optimal pollution level then reads as:

$$P_{opt} = P_{max} - \frac{d + r_{EPI}}{c_p}. \quad P_{opt} = P_{max} - \frac{d + r_{EPI}}{c_p}. \quad (A4.2)$$

Too high reputation losses compared with full pollution avoidance costs and environmental damages lead to a corner solution:  $p_{opt} = 0$ . Assuming sufficiently low reputation losses,  $p_{max} \cdot c_p - d > r_{EPI}$ , matches anecdotal evidence as environmental pollution in reality is not zero. With such a reputation loss, the environmental pollution level in equilibrium tends to be lower than without because managers have an additional incentive to reduce pollution in this case. All further results are in line with the basic analysis: strict liability provides incentives for the realization of the socially optimal pollution level, the precision of the EPI only matters under negligence, the link between the actual pollution level and the EPI's precision is non-monotonic, and manipulation is higher under negligence than it is under strict liability and shareholder benefit from manipulation under negligence.

Also in the case of no liability the pollution level in equilibrium is now lower than without a reputation loss ( $p^*$  equals  $p_{max}$  then):

$$p^* = p_{max} - \frac{r_{EPI}}{c_p}. \quad (A4.3)$$

A positive reputation loss that increases with the reported value of the EPI induces the manager to reduce pollution levels—also in the absence of an effective environmental liability regime. Although shareholders have no reason to provide a compensation scheme that rewards pollution reduction, managers reduce the pollution below the maximum level because of the reputation loss they will suffer.<sup>28</sup>

### *Reputation Loss Due to High Manipulation Levels*

In this section the impact of a reputation loss that is not due to high EPI levels but to the manipulation of the EPI is evaluated. Therefore, two cases will be distinguished: managers' reputation loss due to manipulation and shareholders'

<sup>28</sup> Thus, introducing such a reputation loss excludes the possible corner solution of the basic model that a manager is indifferent between no pollution reduction and the interior model solution.

reputation loss due to manipulation. Both occurred, for example, in the Volkswagen diesel scandal: the resignation of the former Volkswagen CEO Martin Winterkorn came with a severe reputation loss for him as the responsible top manager (Roberts and Rogers, 2018). On the other hand, the drop in share price as a consequence of this scandal is not only due to expected damage compensation payments but incorporates declining sales due to a decrease in trust in the former respected brand (Gomez, 2016). Such a reputation loss affects the shareholder's utility function while the first one alters the manager's utility function. Because the described reputation loss only occurs when there is the possibility of manipulation, the following explanations are based on the extended model.

First, I analyze the impact of managers' reputation loss due to manipulation. Expanding (26) by a reputation loss,  $r_i^M \cdot i$ , where  $r_i^M$  is the incremental reputation loss<sup>29</sup>, results in:

$$EU^M = \bar{s} \cdot \left( \frac{y_S - p + i + \varepsilon}{2\varepsilon} \right) - \frac{1}{2}c_p(p_{max} - p)^2 - \frac{1}{2}c_i i^2 - r_i^M \cdot i. \quad (A5.1)$$

While the reaction function of pollution level  $p(\bar{s})$  remains unaffected, the reaction functions  $i(\bar{s})$  and  $y_S(\bar{s})$  incorporate reputation loss. As can be expected intuitively, the marginal benefit of manipulation decreases if the manager has to incorporate a reputation loss. Thus, a sufficiently high reputation loss mitigates managers' manipulation incentives so strongly that there is no need for shareholders to set a high threshold  $y_S$  for getting the bonus  $\bar{s}$ .

For strict liability and for the no liability case under a negligence rule, the bonus  $\bar{s}$  and, thus, the pollution level in equilibrium are unaffected. Only if the probability of exceeding the permitted pollution level is important, that is, for the second section of the negligence regime, the bonus tied to the EPI increases. Because reputation loss mitigates the incentives for EPI manipulation, lower actual pollution levels need to be realized to lower the probability of exceeding the due diligence threshold. Therefore, shareholders have to offer a higher bonus compared with the situation in which there is no reputation loss. Still, the basic results stated in the main analysis also hold with this model extension.

As a second case, I analyze the impact of shareholders' reputation loss due to manipulation. Accordingly, the managers' utility function is as described in (26) but a reputation loss,  $r_i^S \cdot i$ , where  $r_i^S$  is the incremental reputation loss<sup>30</sup>, is subtracted from the shareholders' expected utility function (7):

<sup>29</sup> The incremental reputation loss,  $r_i^M$ , can be interpreted as the maximum reputation loss,  $R_i^M$ , divided by the maximum manipulation level  $i_{max}$ . A reputation loss of  $r_i^M \cdot p$  ensures that if the manipulation is maximal, the reputation loss is maximal as well; if it is zero, then no reputation loss is expected.

<sup>30</sup> Analogous to the incremental reputation loss  $r_i^M$ . Please consider footnote 24.

$$EU^s = -\bar{s} \cdot \left( \frac{y_S - p + i + \varepsilon}{2\varepsilon} \right) - \exp.\text{env. damage compensation} - r_i^S \cdot i \quad (\text{A5.2})$$

In this scenario, the reaction functions  $p(\bar{s})$ ,  $i(\bar{s})$ , and  $y_S(\bar{s})$  are the same as in the main analysis of EPI manipulation because managers' utility is untouched by this kind of reputation loss.

Under strict liability, shareholders design a compensation contract that mitigates the incentives for EPI manipulation. Hence, they raise the threshold for the bonus  $y_S$  on the one hand and reduce the bonus  $\bar{s}$  on the other hand. This lowers the manager's marginal benefit for EPI manipulation and, thus, the manipulation level is lower than it is without reputation loss—but it also reduces the marginal benefit of pollution reduction. Therefore, higher pollution levels result. Moreover, shareholders suffer from this reputation loss which is shown by lower shareholders' expected utility compared with the initial analysis of EPI manipulation.

While the same mechanisms apply under a negligence rule when the shareholders can be held liable ( $\text{Prob}(\tilde{y} > y_{opt}) > 0$ ), the results when liability is ruled out ( $\text{Prob}(\tilde{y} \leq y_{opt}) = 1$ ) are not altered by shareholders' reputation loss for manipulation. Since the condition for no liability under negligence,  $p - i + \varepsilon \leq p_{opt}$ , as well as manager's expected utility and, therefore, their reaction functions  $p(\bar{s})$ ,  $i(\bar{s})$ , and  $y_S(\bar{s})$  are unaffected by this reputation loss, all relevant results from the main analysis are again supported. Only shareholders' expected utility decreases because of reputation loss—for a sufficiently high reputation loss even below the expected shareholder utility in the case in which no manipulation is possible. Hence, sufficient shareholder punishment for manipulation of the EPI outweighs the benefit shareholders gain by the managers' EPI manipulation under negligence.

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