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Environmental liability, imperfect information and multidimensional pollution control

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**Environmental Liability, Imperfect Information and
Multidimensional Pollution Control**

by Elga Bartsch

June 1995



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Abstract: *A well known result in the economics of tort law is that in the case of a unilateral stochastic externality both a negligence rule and strict liability are in general able to achieve socially optimal precaution. It will be shown in this paper that this equivalence result does no longer hold if imperfect information and multidimensional pollution control activities are considered. It will turn out that a negligence rule may in fact have an adverse effect on the incentives of a potential polluter, causing an uncertain environmental damage, to take appropriate precaution. The change in incentives can be attributed to two effects: immunisation from potential liability and sharpening of incentives for observable precaution diverting effort from unobservable to observable precaution. A standard of negligence tends to distort the choice among different strategies available in reduction of environmental risks, when pollution control efforts are imperfectly observable to differing degrees. This distortionary effect prevails to an even larger extent if there is no uncertainty with respect to the findings of negligence. Hence, in contrast to one-dimensional models of uncertain negligence, the model presented in this paper implies that when the set of possible strategies in reducing environmental risk is somewhat richer than just a one-dimensional decision, uncertainty in verifying the negligent behaviour may actually improve incentives to take preventive pollution control measures compared to a certain standard of due care. Moreover, the polluter's response to changes in the policy parameters are no longer clear-cut in the way that is indicated by the standard model. Under some circumstances, an increase in the standard of negligence may lead to a decline in the level of precautionary pollution control. Therefore, the environmental policy maker has to be very careful when deciding on an optimal second best policy consisting of a divergence of the standard of negligence from the socially optimal level.*

1 The Problem

Over the past decades environmental liability law has become an increasingly important instrument of environmental policy in most industrialised countries. Due to growing public concern about large scale environmental accidents, many countries introduced specific laws dealing with liability for pollution damages². The United States introduced the Comprehensive Environmental Response, Liability, and Compensation Act (CERCLA) already in 1980, followed by the Superfund amendment. More recently, following some serious damages caused by major oil spills, the Oil Pollution Liability Act of 1990 was enacted. In Germany, an Environmental Liability Law (Umwelthaftungsgesetz) came into force in January 1991.

Liability rules should attribute the damage costs to the economic agent who caused them³. The ex post liability will be anticipated ex ante. This anticipation provides the incentives to take adequate precaution (see Cropper, Oates, [1992], 693). A Pareto-optimal level of environmental risks is achieved if the potential polluter takes into account the expected environmental damages, when deciding upon his economic activities which relate to either the probability or the severity of environmental degradation. Properly designed liability law allow to induce the potential polluter to take the socially optimal level of precaution with respect to the environmental risks involved in his or her activities (see e.g. Siebert [1991; 1995 ch. 8], Schwarze [1993a]). Environmental economists have, therefore, frequently advocated liability as an appropriate policy measure in the control of uncertain environmental damages. Uncertainty with respect to the extent of pollution of environmental media can be due to a number of reasons. Often, not only the exact nature of the environmental problems involved is not completely understood, but also the interaction between different pollutants and their diffusion within environmental media, as well as the accumulation of harmful substances over time, is largely unknown. Moreover, as a variety of environmental accidents on different scales indicates, polluters may only be able to control their emissions of pollutants imperfectly.

From an economic point of view, environmental liability law should aim at two different goals, namely at inducing the polluter to take the efficient level of precaution as well as at sharing environmental risk optimally between involved parties. If these questions are addressed in a situation where there is uncertainty but where environmental policy makers and all economic agents possess complete information, both incentives and risk allocation can be examined separately. It is well known from

¹ I am grateful to Frank Bickenbach and Ralph Heinrich for helpful discussions and comments.

² In the context of this paper the term 'damages' refers to the degree of environmental degradation incurred and therefore has to be distinguished from the use of the term in the law and economics literature where it stands for the compensatory payments the defendant has to make to the plaintiff. These will be referred to as liability payments in this paper. But as the paper ignores possible divergence between the harm done and compensation, there is no quantitative difference.

³ The discussion on the bilateral nature of external effects, first pointed out by Coase [1960] in response to Pigou's earlier analysis (Pigou [1932]), is happily ignored in this paper. Obviously, if there existed no victim suffering harm from pollution there would be no damage. This, of course, raises the question if the polluter or the victim causes the damage; a question that can only be 'answered' by a definition or a value judgement. Unilateral in the context of this paper simply indicates the difference in ability to reduce the damages which occur.

principal-agent theory, however, that, if one allows for asymmetric information, this separation is no longer possible. Then there will in general be a Trade-off between incentives for precaution and optimal risk sharing.

Usually, in the discussion of different liability rules it is taken to be true that, in addition to levels of due care being set at the Pareto-optimal level, all agents involved are completely aware of the relationship between all relevant variables, the value of environmental damages, and the respective probability distribution (cf. Endres [1991]). Unfortunately, in reality, environmental policy makers in designing liability rules lack most of the relevant information they would need in order to ensure a social optimum⁴. Moreover, other variables like the actual level of precaution taken by the potential polluter are only imperfectly observable. One crucial assumption made in most models of environmental liability is that activities in precaution are observable. This constitutes a very strong idealisation. In the case of many environmental problems, it is much more likely that this information is at least to some degree private to the polluter. Hence, environmental policy makers face a situation where there is not only uncertainty about the extent of environmental damages that will occur but where there is also asymmetric information with respect to the measures taken by potential polluters to reduce environmental risks⁵.

In this paper it will be assumed that the level of preventive activities cannot be observed exactly. It will be shown that the standard result of the economic theory of tort law that a negligence rule is in general able to achieve the socially optimal level of preventive activities by the potential injurer causing the stochastic externality, does no longer hold when multidimensional precaution in pollution control and imperfect information are considered. In order to understand the consequences of incomplete standards of negligence more precisely, a simple model will be presented, which takes into account multiple strategies in pollution control of the potential polluter using the idea developed by Holmström, Milgrom [1991] in the context of a principal-agent problem. The model allows for differing degrees of observability of the activities. It is reasonable to suppose that some activities like the installation of pollution control equipment are easier to monitor than others, such as management techniques, supervision and training of employees or the carefulness of the workers in charge. The consequences of different liability rules on the efficient combination of precautionary activities will be discussed. It will be shown that a negligence rule may have perverse effects on the incentives to take precaution. Whether adverse effects will emerge when the polluter has multiple

⁴ This is in particular true for the information required to set a Pareto-optimal standard of due care. Instead, most of the information, e.g. costs of pollution control or the monetary evaluation of the damages incurred, has to be provided by either the polluter or the pollutee. This gives rise to the problem of truthful revelation of such information to environmental policy makers or the court (see Jost [1995] or for a more general treatment Emons [1993]). This information asymmetry constitutes a crucial difference between environmental pollution and most other accidents (cf. Kirchgässner [1992]).

⁵ Models of asymmetric information have been adopted by environmental economists only to a limited extent. The existing literature is mostly concerned with the extraction of private information from self-interested individuals (cf. Dasgupta, Hammond, Maskin [1980], Kwerel [1977], Spulber [1988], Emons [1993]), the possible consequences of uncertainty with respect to costs and benefits of pollution abatement on the optimal policy (cf. Weitzman [1974], Roberts, Spence [1976], Baumol, Oates, [1988], ch. 13), and, more recently, with the issue of unobservable individual emissions in non-point-source pollution (like the volume edited by Dosi, Tomasi [1994]).

options of preventive pollution control measures, depends on the relationship between different types of pollution control effort, i.e. whether different strategies in reducing environmental risk exposure are substitutes or complements. A central feature of a standard of negligence is that it might provide stronger incentives for observed care. A negligence rule creates two effects when precautionary efforts are only imperfectly observable: on the one hand a polluter, that has violated the legally prescribed environmental safety standard may not be held liable. On the other hand, it opens the possibility to influence the chances of being held liable. Whereas the first effect weakens the incentives to take precaution, the second effect strengthens the incentives for those dimensions of precautions for which a standard of due care is defined. The relative strength of the two effects determines whether the polluter will take higher or lower precaution under a negligence rule than is socially optimal. The incentives to take unobservable effort, however, are weakened. These effects may be reinforced or counteracted by the interdependence between different control strategies.

1.1 Informational Problems in Environmental Liability

Most of the literature on economics of liability law considering informational problems focuses on the problem of incomplete information. It deals with the problem of incomplete information in the context of the possible equilibrium effects of either a incorrectly set standard of due care under a negligence rule, or the consequences of possible misperceptions in the risk assessment by the polluter in regard to the possible effects of his or her activities. The question is then asked how sensitive the precaution incentives are to these errors. It turns out that strict liability is highly sensitive in regard to any misperception of risk as well as any other imperfection that causes a divergence between the true environmental risk involved and the expected compensation payments. Here, a negligence rule provides immunisation from moderate misassessment of risk. When the underestimation of the potential risk is sufficiently large, however, the polluter may choose not to take the legally prescribed level of precaution (see Endres [1989], Heyn [1993]).

If under a negligence rule the standard of due care is set incorrectly, a number of different cases have to be distinguished. Depending on whether the environmental policy makers made a considerable mistake in determining the standard of due care such that the standard is set substantially above the optimal level, the polluter may prefer to violate the standard and to face compensatory payments instead. If this is the case, there will not arise a distortionary effect as the polluter then faces expected compensation payments which are equal to environmental damages and is, thereby, induced to take optimal care. If the standard is only moderately too high, polluters may prefer to stick to the level of precaution prescribed by the liability law. Whether this will be the case, depends on the size of distortion in the determination of the standard of due care, the costs of prevention and the expected environmental damage. Whenever the standard is set too low, the polluter will just comply with it. In this case, preventive activities will always be lower than in the social optimum.

1.2 Multidimensional Activities in Pollution Control

Most models of accident liability assume that the potential polluter has only one possible precautionary activity at hand to reduce environmental risks. Although this assumption may be useful to keep the analysis straightforward in many questions, it neglects a substantial problem. When the agent faces a whole variety of possible measures to reduce the risk of emitting dangerous substances to the environment, the definition of a standard of due care under a negligence rule will frequently not be able to cover all of them (see Endres [1991]). It is, for example, reasonable to assume that not only the level of precaution, i.e. the pollution control equipment installed, but also the level of the activity which generates the environmental risk, i.e. the time for which the plant operates, determines expected environmental damages. Both measures should be combined in such a way that total costs of risk reduction are minimised in the efficient reduction of environmental risks. However, a negligence rule will only provide incentives for those activities defined in the standard of due care. In a more general perspective, it is obvious that it will be impossible to define an optimal standard of negligence for every possible strategy of reducing environmental risks⁶. For this reason, the negligence rule has been criticized by Shavell [1980], who shows that it does not provide the correct incentives with respect to the activity level generating the stochastic externality. Although an appropriately set negligence standard may induce the socially optimal precaution, the level of the economic activity, e.g. the level of production, will tend to be too high in equilibrium. Hence, the output of the polluting industry will be too high and the number of firms in the market will be too large in the long run. Therefore, as Polinsky [1980] pointed out, the price of the good consumed is too low, and the good will accordingly be consumed in too high amounts. With a perfectly functioning strict liability, by contrast, environmental damages will be internalised fully and, hence, transformed into correct consumer prices.

The remainder of the paper is organised as follows. The basic framework of the model is laid out in the next section. In section 3, the optimal effort levels in precautionary pollution control activities from the point of view of the potential polluter under different liability rules as well as the socially optimal precaution levels are derived. A second approach frequently chosen in environmental policy in order to reduce risk exposure, namely environmental safety regulation, is discussed in section 4. The main conclusions are summarised in section 5.

2 The Basic Framework

In setting liability rules, the environmental policy maker acts as the principal. The potential polluter, being the agent, carries out the task of reducing uncertain environmental degradation on behalf of the principal. When setting liability rules, the environmental policy maker is assumed to behave as a perfect representative of the victims' interests. Free-rider problems among injured parties which would prevent them from bringing cases to trial are neglected. Courts are assumed to enforce the liability

⁶ These considerations may also be extremely relevant for technical progress induced by environmental legislation. Under a negligence rule, pollution control technologies are pinned down by the standard of due care. Hence, there is no incentive for an upgrading in technology. Only with respect to cost reducing technical progress, proper incentives prevail.

rules perfectly and costlessly⁷. Moreover, it will be assumed that all potential polluters face the same cost of pollution control function and the same uncertain liability payments, thereby avoiding problems that arise if a single legal standard is applied to heterogeneous defendants. The model used here is similar to a principal-agent model with moral hazard, where the actions taken by the agent cannot be observed perfectly by the principal.

The stylised timing of the interaction between the environmental policy maker and the polluter can be modelled as follows. In the first step, the environmental policy maker in setting the liability rule determines the incentive scheme. Given these liability rules, the polluter chooses the optimal precaution measures from his point of view. Nature moves next, drawing a state of the world from a known probability distribution. Both preventive activities and the actual state of the world determine the environmental damage that will be publicly observed. Depending on these observed damages and, in the case of a negligence rule, some other publicly observed signal, compensatory payments are made according to liability rules set initially.

Often, a potential polluter can engage in more than one type of effort in reducing the probability and the extent of an environmental accident, where some effort types are easier publicly observable than others. The reason for this might be either that the policy maker may find it too costly to monitor all activities or that they are simply unobservable as in non-point-source pollution. In the model used in this paper the potential polluter can exert two different kinds of effort, e_1 and e_2 , in order to reduce environmental risks, where e_1 is level of observable precaution and e_2 the level of unobservable precaution. Precautionary efforts influence both the probability of an environmental accident and the magnitude of environmental degradation. Together with a random variable, θ , describing the stochastic influence factors that might affect the actual level of degradation for a given level of precautionary efforts, these precautionary efforts in pollution control determine the actual environmental damage $d(e_1, e_2; \theta)$ for a given state of the world θ , with θ being a normally distributed random variable with a zero mean. Let expected environmental damages $D(e_1, e_2)$ be downward sloping⁸. $D(\cdot)$ is a strictly convex function by assumption, so the marginal effect on

⁷Free-rider problems and the cost of litigation are neglected, not because the author believes that they are not important, but in order to focus the analysis on incentive problem on the polluter's part. For models with costly litigation are discussed by P'ng [1987], Polinsky, Rubinfeld [1988]. For the purpose of this paper, it is irrelevant whether the liability payments are made to the public treasury or are used to compensate the victims of pollution. For simplicity, it is assumed that potential victims of environmental pollution always take the socially optimal level of precaution. Although many authors consider explicitly the level of precaution taken by the potentially injured party, in the case of environmental problems risk reduction by the pollutees seems to be of minor importance and is, therefore, ignored. Note that in the Anglo-American system of case law, it is the court who basically sets the incentive mechanism, whereas in the system of Roman law the government determines the rules of the game. A discussion of the institutional framework of environmental liability is found in Zweifel, Tyran [1994].

⁸The random variable θ will be suppressed in the following as throughout the paper, it will be assumed that all economic agents are risk neutral. In order to have a meaningful information asymmetry in the model, it is necessary that this stochastic influence cannot be observed. Otherwise, the missing information can be inferred from observing the stochastic factor, the damage, and the observable precautionary efforts.

expected environmental damage diminishes if the level of one effort type is increased. Carrying out pollution control activities involves some cost to the polluting firm. With respect to the disutility of effort function of the polluter, $f(e_1, e_2)$, it is assumed that the cost of precaution increases if the total effort increases. The cost function is assumed to be strictly convex (i.e. marginal cost increase with increasing effort level). Strict convexity of expected environmental damages and the cost of precaution function imply that the total cost function, $D(\cdot) + f(\cdot)$, is also strictly convex⁹. Consequently, a unique minimum exists, once first-order conditions are met.

3 Liability Rules and Incentives for Precaution

The polluter's choice of preventive measures depends on the liability rule chosen by the environmental policy maker. Under a negligence rule, payments will only be awarded if the court finds the defendant negligent. Under a strict liability rule, the court will award compensatory damage payments according to the environmental damage incurred. In presence of uncertainty and asymmetric information with respect to the action the polluter has taken, the core of the analysis is the issue of incentive compatibility, i.e. the optimising behaviour of the agent given the incentive scheme. This reaction of the potential polluter to different liability rules will be derived below.

3.1 Socially Optimal Precaution

Before analysing the reaction of the potential polluter to different forms of liability in more detail, the level of reference with respect to precautionary activities is determined by assuming absence of informational asymmetries. With complete information, a risk-neutral social planner will minimise total expected costs of environmental damage which consist of expected environmental damage, $D(\cdot)$, on the one hand, and the cost of precaution, $f(\cdot)$, on the other hand

$$\text{Min } SC(e_1, e_2) = D(e_1, e_2) + f(e_1, e_2).$$

The first-order conditions for optimal level of precautionary pollution control under full information are given by

$$D_1 + f_1 = 0$$

$$D_2 + f_2 = 0.$$

Thus, the socially optimal effort levels of the potential polluter are given by the equality of marginal damage prevented (the negative of the marginal expected cost of environmental degradation) and the marginal cost of pollution control. In the absence of informational problems the socially optimal precaution level can be implemented by

⁹ The expected damage (cost) function is strictly convex of $d^2 D > 0$ ($d^2 f > 0$), that is, if the Hessian matrix is positive definite. The Hessian will be positive definite if the first principal minor is positive ($D_{11}, f_{11} > 0$), and the determinant of the matrix itself is positive, i.e. $D_{11} D_{22} - D_{12}^2 > 0$ and $f_{11} f_{22} - f_{12}^2 > 0$ with $D_{12}, f_{12} < 0$ or > 0 , provided that $f_{12} = f_{21}$ and $D_{12} = D_{21}$ which by Young's theorem will be the case. It follows from this that f_{22} and D_{22} are also positive. In fact, for the total cost function to be strictly convex only one of the two functions has to be strictly convex, provided that the other is convex.

means of a forcing contract. Any deviation from first best effort levels will be detected immediately and will be sanctioned such that the polluter will comply.

3.2 Negligence Rule

Under a negligence rule, compensatory damage payments are awarded if the perceived care is smaller than a given standard of due care. A basic result in economics of tort law is that, if the legal standard is defined at the socially optimal level and the polluter knows that standard with certainty (and there are no other informational problems present), a negligence rule is able to achieve efficient precaution¹⁰. Now, the somewhat more realistic assumption is made that there is uncertainty involved about the findings of negligence¹¹. Then, for a given level of precaution taken the polluter is uncertain if he is going to be found negligent in litigation. This may be caused by an uncertain decision of court on the standard of due care if the court's interpretation of the evidence is not known perfectly beforehand¹². The uncertainty over the findings of negligence in this model, by contrast, is due to imperfect observability of pollution control activities. Here, monitoring problems in the court's determination of observable precaution taken by the polluter arise. Following this approach, the courts may err in assessing the true level of care since only an imperfect signal s_i of the actual effort exerted can be observed. Suppose that the court can only observe $s_i = e_i + \varepsilon_i$, where ε_i is a normally distributed, zero mean random variable. The polluting firm will be held liable if and only if $s_i < n$.

The liability rule $l(s_i, e_i)$ for a given standard of due care in the case of a negligence rule is given by:

$$l(s_i, e_i, \varepsilon_i) = \begin{cases} 1 & \text{if } s_i(e_i) < n \\ 0 & \text{otherwise.} \end{cases}$$

Polluters who are found negligent are assumed to be assessed the full external costs of their economic activities by means of liability payments that are equal to the environmental damage caused. Hence, provided that θ and ε_i are stochastically independent, the total expected cost of the polluting firm under a negligence rule is

$$TCN = E(f) + l(s_i, e_i, \varepsilon_i) D(e_i, e_2).$$

¹⁰ Provided that the standard defining negligent behaviour covers all possible dimensions of risk reduction in an optimal way.

¹¹ Equally, one can take into account the possibility that the polluter is unable to control his level of care completely. In this case it is necessary to distinguish between the level of care at the moment the accident happens and precaution which is only stochastically related to care (cf. Diamond [1974], 109). In this paper both terms, care and precaution, are used synonymously.

¹² The case of one-dimensional precaution activities has been analysed extensively in the literature. Diamond [1974] looks at uncertainty with respect to how precautionary measures translate into safety levels. Uncertain legal standards with one-dimensional care have also been analysed by Calfee, Craswell [1986]. Cooter, Ulen [1986] examine uncertainty in the court's interpretation of the evidence. Uncertain court decision have been analysed formally by Kolstad Ulen, Johnson [1990].

The moment at which the potential polluter takes the decision about the appropriate level of precaution, he faces some unavoidable uncertainty because he controls the observable signal only imperfectly. Hence, the polluter is not fully immunised against being held liable. Even if the polluter takes a sufficiently high level of observed precaution, there is still a positive probability that he will be held liable. Let $G(s_i|e_i)$ be a continuously differentiable distribution function, with a density function, $g(s_i|e_i)$ according to which the imperfect signal of precautionary efforts is distributed. The probability that the polluter in litigation will end up with a perceived level of precaution lower than n and therefore will be held liable is given by

$$p(s_i < n) = p(e_i + \varepsilon_i < n) = \int_{-\infty}^{n-e_i} g(\varepsilon_i) d\varepsilon_i = G(n-e_i)$$

This is the probability that the polluter has to cover damages $D(\cdot)$. Rewriting total cost for the case of a negligence rule gives

$$TCN = f(e_1, e_2) + D(e_1, e_2)G(n - e_1)$$

For analytical convenience, the assumption is made that TCN is strictly convex. The first-order conditions for a cost minimum of a risk-neutral polluter are then

$$f_1(e_1, e_2) + D_1 G(n - e_1) - D(\cdot)g(\cdot) = 0$$

$$f_2(e_1, e_2) + D_2 G(n - e_1) = 0$$

provided that $e_1, e_2 > 0$ at the optimum¹³.

Again at the cost-minimising levels of precaution, the marginal cost of precaution have to equal the marginal change in expected liability payments. The change in expected damage payments can be decomposed into two separate effects which indicate the impact of a marginal increase in precautionary effort on expected liability payments. The "damage effect", $D_1 G(\cdot)$, consists of the marginal reduction in expected environmental damage, multiplied by the probability of being held liable. This effect is relevant for the optimal choice of both effort types. Due to the fact that $G(\cdot) < 1$, the incentives to take both types of precautionary measures under a uncertain negligence rule are weakened compared to the social optimum. The reason for this is that a negligence rule shelters the polluter partly from being held liable, even if only imperfectly, because of the uncertainty involved. If this were the only effect present, as

¹³ Here, it is assumed that $e_1, e_2 > 0$ at the minimum. As it will turn out later, under some circumstances the polluting firm might choose $e_2 = 0$. To include the possibility of boundary solution, the minimisation problem can easily be rewritten, as $f_1 + D_1 \geq 0$, $e_1 \geq 0$ with the additional complementary slackness conditions $e_1(f_1 + D_1) = 0$, and $i = 1, 2$. A corner solution, $e_1 = 0$, can occur if the first unit of precaution does not reduce expected liability payments enough to match the cost of precaution caused by this first unit of effort. To restrict the analysis to interior solutions, it will be assumed that this case does not arise as long as there is some uncertainty involved in the findings of negligence. This presumption will, however, not be valid under a certain but incomplete negligence rule with perfect observability of one precaution type. Here, the polluter optimally chooses $e_2 = 0$. Under an uncertain negligence rule, the incentive to take an unobservable pollution control measure arise from the fact that no matter what level of e_1 the potential polluter takes, there is a positive probability that he will be held liable for the damage caused. Hereby, some incentive to reduce damages effectively by also exerting e_2 is generated.

in the optimality condition for unobservable effort, e_2 , the polluter would unambiguously choose a lower level of precaution than the socially optimal level.

The "liability effect", $-D(\cdot)g(\cdot)$, influences only the optimal value of the observable effort. It indicates the savings in expected liability payments due to a decreased probability of being held liable when observable precaution is increased¹⁴. As the marginal probability of being held liable is $-g(n - e_1)$, the potential polluter can reduce the chance of being found negligent by increasing the level of observable precaution. The marginal change in the Likelihood of being found negligent is weighted by the total damage caused for which the polluter might be held liable, if he is found negligent. This implies that incentives to take observable precaution measures are sharpened under a negligence rule. As the liability effect tends to offset the damage effect, under a negligence rule, there are two effects of opposite signs that have to be considered influencing the optimal choice of e_1 . Whether or not e_1 rises as a net result of these two offsetting effects will depend on the relative size of the damage effect versus the liability effect¹⁵. The net effect will depend on various factors, such as the cost of precaution, the liability payments the polluter has to face when found negligent, the degree of uncertainty in assessing the level of observable precaution, the risk-attitude of the polluting firm, and the interdependence between the different dimension of pollution control activities. For the observable precaution, type both a higher and lower level than the social optimum are in general possible. For the unobservable type, the cost-minimising level will be unambiguously lower than the social optimum.

However, as both first-order conditions have to be satisfied simultaneously, changes in the optimal level of one effort type will change the optimal level of the other effort type. Thereby, depending on whether different strategies in pollution prevention are substitutes or complements, the effects described above may be reinforced or partly offset by the interdependence of optimal precaution levels. This points to the fact that the consequences of a negligence rule are even more complex than the first-round impacts discussed above. These interdependencies in the optimal choice of the two pollution control activities are discussed in the next section.

3.2.1 Optimal Interdependent Choice of Pollution Control Measures

Changes in the incentives for one type of precautionary effort will affect the level of the other effort type chosen by the potential polluter via induced changes in marginal cost and the marginal expected damage that can be prevented by an extra unit of precaution. With respect to the interaction between different pollution control strategies, two cases have to be distinguished with respect to cross derivatives of the respective functions. If efforts are substitutes, ($f_{12} > 0$, $D_{12} > 0$), the marginal cost of (marginal damage prevented by) carrying out one type of precaution rises (decreases in absolute terms)

¹⁴ As marginal environmental damage is negative and the probability of being held liable is positive, the damage effect is always negative. So is the liability effect (excluding the minus in front), as the damages and the density function are both positive.

¹⁵ Whether or not the incentives to exert observable effort are sharpened or weakened can be distinguished by evaluating the first-order condition under a negligence rule at the social optimum, where $-D_1 = f_1$. This gives $D_1(G-1) - D(\cdot)g < \text{or} > 0$. As the first term on the LHS is positive, this reflects the reduction in incentives to take precaution and vice versa for the second term. For $-D_1(G-1) > 0$, and, hence, a decline in the optimal level of unobservable precaution.

with an increasing level of the other effort type. If, on the other hand, efforts are complements, marginal cost (marginal effectiveness) of one effort type decline (rises) as the level of other type increases, ($f_{12} < 0, D_{12} < 0$).¹⁶

Let $e_i(e_j)$, $i=1,2; j=1,2; j \neq i$, denote the optimal level of effort type i for given a level of the other effort type j . Upper index N indicates the case of a negligence liability rule whereas S indicates the socially optimal solution, i.e. the first best case. To compare the incentives to allocate efforts among different pollution control activities, the first-order conditions for a cost minimum are differentiated with respect to the other choice variable. For observable precaution after rearranging terms, this yields the slope of the optimal effort function, $e_i^s(e_j)$. In the full information case this is

$$de_i/de_j = (-D_{12} - f_{12})/(D_{11} + f_{11}).$$

In order to be able to separate possible interdependencies, it is assumed that either $D_{12} = 0$ or $f_{12} = 0$. As the damage and the cost function satisfy $D_{11} > 0, f_{11} > 0$, this implies that

$$de_i/de_j < 0 \quad \text{if} \quad f_{12} \text{ or } D_{12} > 0 \quad \text{substitutes}$$

$$de_i/de_j > 0 \quad \text{if} \quad f_{12} \text{ or } D_{12} < 0 \quad \text{complements}$$

The optimal observable precaution level, will fall, when the level of unobservable precaution rises if the two effort types are substitutes. Whereas, in the former case, the rise in marginal cost reduces optimal value of e_i , in the latter case, the decrease in the marginal damage prevented makes exerting e_i less and less attractive. An analogous relation holds for the case of complementary efforts. The same sort of reasoning can be applied to the slope of the optimal level of unobservable pollution control curve, $e_2^s(e_1)$

$$de_2/de_1 = (-D_{12} - f_{12})/(D_{22} + f_{22}).$$

Hence, in the social optimum, the optimal level of both effort types increases (decreases) with the level of the other effort exerted, when the two pollution control activities are complements (substitutes).

Under a negligence rule differentiation of the first-order condition for optimal observable precaution gives

$$[D_{11}G(n - e_1) - D_1g(n - e_1)]de_1 - [D_1g(n - e_1) - D_1g'(n - e_1)]de_1 + f_{11}de_1 + [D_{12}G(n - e_1)]de_2 - D_2g(n - e_1)de_2 + f_{12}de_2 = 0$$

¹⁶ Both interdependencies reflect the same interrelation. On the one hand, marginal effectiveness of one precaution type is increased (decreased), on the other hand, the marginal cost of exerting one type of effort varies with the level of the other precautionary effort. But the interpretation is different, as the sign of the first derivatives differ: $f_{12} > 0$ means that marginal costs of one type increase as the level of the other effort rises (substitutability). If $D_{12} > 0$, this reflects the fact that the marginal damage that can be prevented by increasing one effort type, declines with the level of the other effort type that is exerted (note that the marginal damage prevented is negative).

$$\frac{de_1}{de_2} = \frac{D_2 g(\cdot) - f_{12} - D_{12} G}{D_{11} G(\cdot) - 2D_{12} g(\cdot) + D g'(\cdot) + f_{11}}$$

The denominator is positive, as long as $g'(\cdot)$ never takes a large negative value, because the other terms are unambiguously positive. If the density function g is single-peaked, this corresponds to the assumption that the marginal Likelihood does not decrease rapidly at values above the value at which it peaks. For the remainder of the paper this will be assumed to be the case.

Hence, for the case of substitutable efforts ($f_{12} > 0, D_{12} > 0$), $de_1/de_2 < 0$ unambiguously: in the case of substitutes the optimal level of observable effort under negligence will decrease with rising e_2 . If efforts are complements, ($f_{12} < 0$), two cases have to be distinguished, as in this case, the numerator may be positive or negative. If the indirect effect of changes in unobservable effort on the profitability of observable precaution via changes in expected liability payments is smaller in absolute terms than the effect via changes in marginal cost, i.e. $|D_2 g(\cdot)| < |f_{12}|$, then e_1 will increase with rising e_2 and vice versa. If $D_2 g(\cdot)$ is larger than f_{12} in absolute terms, which implies that a change in e_2 has a bigger impact on marginal expected liability payments than on marginal cost, then $de_1/de_2 < 0$. The counter-intuitive result may emerge, that optimal observable precaution is inversely related to unobservable precautionary effort, although both are complementary to each other.

With respect to unobservable care differentiation in the case of a negligence rule being applied, yields

$$[D_{11}G(n - e_1) - D_{12}g(n - e_1)]de_1 - [D_{12}g(n - e_1) - Dg'(n - e_1)]de_2 + f_{11}de_1$$

Rearranging gives the slope of optimal unobservable effort as a function of observable precaution, $e_2^N(e_1)$

$$\frac{de_2}{de_1} = \frac{D_2 g(\cdot) - f_{12} - D_{12} G}{D_{22}(G(\cdot)) + f_{22}}$$

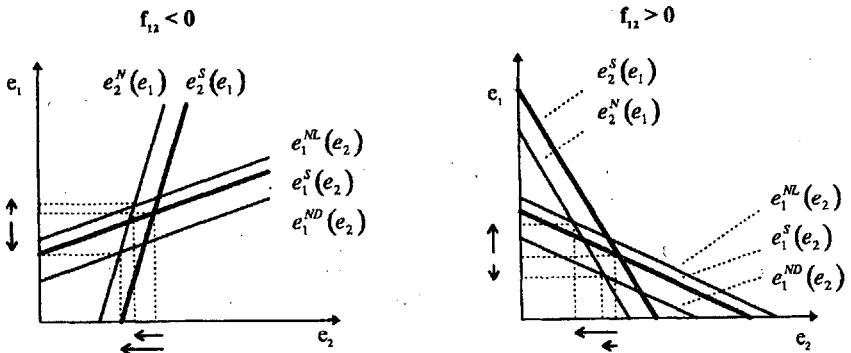
The sign of this slope will, again, depend on the difference between the cross-derivative of the cost of precaution function and $D_2 g(\cdot)$. Again the numerator will be unambiguously negative if $f_{12} > 0$. For the case of complementary pollution control strategies two cases have to be distinguished. Table 1 summarises the interdependencies of the optimal choice variables under negligence liability compared to the social optimum.

Table 1 : Indirect effects on the choice of precaution levels¹⁷

	Full information	Negligence rule
$f_{12} > 0$	$de_1/de_2 < 0, de_2/de_1 < 0$	$de_1/de_2 < 0 \quad de_2/de_1 < 0$
$f_{12} < 0$	$de_1/de_2 > 0, de_2/de_1 > 0$	$ D_2g(\cdot) > f_{12} , D_2g(\cdot) < f_{12} $ $de_1/de_2 > 0 \quad de_1/de_2 < 0$ $de_2/de_1 > 0 \quad de_2/de_1 < 0$ (regular) (irregular)

The total impact of a negligence rule in a situation of imperfect observability of precautionary measures depends both on the direct impact and the indirect impact caused by the interdependencies between both types of pollution control measures. The analysis of the precautionary implications of a negligence rule is further complicated by the ambiguous direct effect on observable precaution if the care taken is only imperfectly observable by the court. It has turned out that the polluting firm might take higher or lower precaution of the observable type under a negligence rule than it is socially optimal. Thus, according to the ambiguous relation among optimal effort levels, four cases have to be distinguished.

Figure 1 : Illustration of the overall impacts of negligence



The different cases are illustrated in Figure 1. As it has been derived above, in the case of substitutes, the optimal choice functions are negatively sloped, whereas in the case of complements they will have a positive slope. Again, superscript S denotes the first-order conditions for a social optimum. The optimality conditions under a negligence rule are indicated by superscript N. The damage effect will c.p. lead to an inward shift

¹⁷ The distinction between the different cases also holds for $D_{12} > 0$ and $D_{12} < 0$, respectively. Then, however, the distinction between regular and irregular cases when efforts are complements, will depend on whether $-D_2g$ is $>$ or $< |GD_{12}|$.

of the optimal choice functions. Whereas, consequently, the $e_2(e_1)$ curve shifts unambiguously to the left. By contrast, the $e_1(e_2)$ curve is subject to the counter-acting liability effect, which c.p. will shift this curve to the right. Therefore, in the case of a dominant damage (liability) effect, this curve will shift to left (right), denoted in the diagram by $e_1^{ND}(e_2)$ and $(e_1^{NL}(e_2))$ respectively. A dominant damage effect will, in the case of substitutes, lead to moderate reductions of both effort types. In the case of complements, by contrast, the cost-minimising levels of both effort types will decrease more for a given shift of the optimal choice functions. In this case, the damage effect will be reinforced by the interdependence between different pollution control strategies. By the same reasoning, a dominant liability effect, raising e_1 , will be reinforced when different strategies in precaution are substitutes. The overall precautionary effects of an incomplete negligence rule, when efforts are imperfectly observable, are summarised in Table 2.

Table 2: Precautionary efforts under a negligence rule¹⁸

	Negligence Rule	
	dominant damage effect	dominant liability effect
observable effort	$e_1^N < e_1^S$	$e_1^N > e_1^S$
unobservable effort	$f_{12} > 0$ (substitutes) $e_2^{NL} < e_2^{ND} < e_2^S$	$f_{12} > 0$ (substitutes) $e_2^{NL} < e_2^{ND} < e_2^S$
	$f_{12} < 0$ (complements) $e_2^{ND} < e_2^{NL} < e_2^S$	$f_{12} < 0$ (complements) $e_2^{ND} < e_2^{NL} < e_2^S$

Whether the environmental risk involved will increase in the case of a dominant damage effect as a consequence of the introduction of a negligence rule depends on the induced change in unobservable effort and the relative importance of unobservable effort in preventing accidental environmental degradation. Risk will rise more in case of the efforts being complements, whereas in the case of substitutes the overall adverse impact on precaution is less pronounced. A reduction in environmental risk is more likely if the liability effect dominates and precautionary efforts are complements.

3.2.2 Comparative Static Analysis

The cost-minimising levels of precaution will vary with the cost of precaution, the potential environmental degradation, the degree of uncertainty in observing the effort of the polluter to control the emission of hazardous substances, and the definition of the standard of due care. In order to analyse the respective impacts of changes in the ecological risk or the cost of reducing this risk, parameters are introduced to represent exogenous factors which determine precaution costs, and expected damage. Let b denote a parameter indicating the risk potential for the environment, such that $D(e_1, e_2; b)$

¹⁸ Only the regular case is considered.

with $D_b < 0$. That is to say that the marginal damage that can be prevented by increasing precautionary effort will decline when the background level of environmental degradation increases¹⁹. Similarly, let c denote exogenous influences in the cost of pollution control function, such that $f(e_1, e_2, c)$, with $f_c > 0$. The standard of negligence is a parameter of the environmental policy maker. It will turn out that when information problems are present, the reaction of a potential polluter under a negligence rule might differ from the response that is socially optimal.

One other important factor in this context is the degree of uncertainty in observing the level of precaution. As the observable precaution type becomes less precisely observable, the density function, $g(\cdot)$, becomes relatively flat. In similar models of one-dimensional precaution, the result has been established that for low degrees of uncertainty the liability effect will dominate (see for example Kolstad, Ulen, Johnson [1990, Shavell [1987], and Craswell, Calfee [1986]). When the distribution is extremely dispersed, a given change in the level of pollution control will have a relatively small impact on the Likelihood of being found negligent. The higher $-g(n - e_1)$ in absolute terms, the more likely it is that the level of observable effort is higher under a negligence rule than in the social optimum. In the one-dimensional case, overinvestment in observable pollution control effort relative to the social optimum will occur, i.e. too much pollution control equipment like e.g. filters will be installed, if there is only a low degree of uncertainty. By contrast, in the model presented here, an increase in uncertainty will entail two opposing effects, a negative impact on the incentives to take observable precaution and a positive impact on the incentives to take unobservable precaution. This is due to fact that the incentives to take unobservable effort are weakened when the uncertainty involved in the determinance of negligent behaviour decreases²⁰. In this sense, an information asymmetry may actually improve the situation regarding incentives for unobservable pollution control activities. The role of uncertainty will be discussed in section 4.

Implicit total differentiation of the first-order conditions under a negligence rule gives

$$\begin{aligned} & \{D_{11}G(n - e_1) - D_{12}g(n - e_1) - [D_{12}g(n - e_1) - Dg'(n - e_1) + f_{11}]\}de_{11} \\ & + \{D_{12}G(n - e_1) - [D_{22}g(n - e_1) + f_{12}]\}de_2 \\ & = -D_{1b}db - f_{1c}dc - (G_n D_1 + g_n D)dn \\ & [D_{22}(G(n - e_1))]de_2 + f_{22}de_2 + [D_{21}G(n - e_1) - g(n - e_1)D_2]de_1 + f_{21}de_1 \\ & = -D_{2b}db - f_{2c}dc - G_n D_2 dn. \end{aligned}$$

¹⁹ Note that b can also be a policy parameter, as it is at the law makers disposition which kinds of harm will lead to compensation. Moreover, it will be implicitly assumed that parameter b does not influence the total damage.

²⁰ When there are no monitoring problems involved in determining the effort e , taken by the polluter, he will exert no unobservable effort at all, as complying to the standard of due care immunises completely from being held liable.

where G_n and g_n indicate the partial derivatives of the distribution function and the density function with respect to the standard of negligence, with $G_n > 0$, $g_n > 0$ if $n < e_1$ and $g_n < 0$ if $n > e_1$.

Solving for de_1/dn and de_2/dn by applying Cramer's rule, shows that the effect of a variation of the standard of negligence on precautionary efforts is not clear-cut. In fact, the counter-intuitive result may arise, that precautionary efforts decline as response to an increase in the legally prescribed level of due care.

$de_1/dn > 0$, $de_2/dn > 0$ if

$$[(-G_n D_1 + g_n)(D_{22}G + f_{22})] - [(-G_n D_2)(D_{12}G - D_2g + f_{12})] > 0$$

$$[(D_{11}G - 2D_1g - D_2g' + f_{11})(-G_n D_2)] - [(D_{12}G - D_2g + f_{12})(-G_n D_1 + g_n D)] > 0$$

$$g_n > 0 \text{ and } f_{12} < 0 \text{ and } |f_{12}| > |D_2g|, D_{12} = 0$$

$$D_{12} < 0 \text{ and } |D_{12}| > |D_2g|, f_{12} = 0$$

or

$$g_n < 0 \text{ and } f_{12} < 0 \text{ and } |f_{12}| > |D_2g|, D_{12} = 0$$

$$D_{12} < 0 \text{ and } |D_{12}| > |D_2g|, f_{12} = 0.$$

$$\text{and } |-G_n D_1| > |g_n D|$$

However,

$de_1/dn < 0$, $de_2/dn < 0$ if

$$g_n < 0, |-G_n D_1| < |g_n D|, f_{12}, D_{12} \geq 0.$$

or

$$g_n < 0, |-G_n D_1| < |g_n D|, f_{12}, D_{12} \leq 0$$

$$\text{and } |f_{12}| < |D_2g|.$$

If one interprets $g_n < 0$ as overcompliance with the legally prescribed environmental safety standard prescribed in the initial equilibrium ($e_1 > n$)²¹, then in the case of initial overcompliance a further increase in the standard of negligence will, under the conditions described above, lead to a reduction in precautionary efforts. Only, in the case of initial undercompliance or a dominant damage effect, a more stringent standard of due care may induce unambiguously higher precaution by the polluter. In a special case, this increase may also arise if the polluter initially already overcomplied with the standard.

The effects of a change in the degree of potential environmental degradation can be easily obtained by the using the same procedure:

$$de_1/db > 0 \quad \text{if } -D_{1b}(f_{22} + GD_{22}) - [-D_{2b}(f_{12} - D_2g + GD_{12})] > 0$$

$$\text{hence, } de_1/db > 0$$

²¹ If the standard initially was set at the social optimal level of e_1 , this corresponds to the case of a dominant liability effect.

$$\text{if } f_{12}, D_{12} \geq 0^{22}$$

$$\text{or } f_{12} < 0 \text{ and } |f_{12}| < |-D_2g|, D_{12} = 0$$

$$D_{12} < 0, \text{ and } |GD_{12}| < |-D_2g|, f_{12} = 0$$

$$de_1/db > 0 \quad \text{if } -D_{22}(f_{11} + D_{11}) - [-D_{12}(f_{12} - D_2g + GD_{12})] > 0$$

$$\text{hence } de_1/db > 0$$

$$\text{if } f_{12}, D_{12} \geq 0$$

$$\text{or } f_{12} < 0 \text{ and } |f_{12}| < |-D_2g|, D_{12} = 0$$

$$D_{12} < 0 \text{ and } |GD_{12}| < |-D_2g|, f_{12} = 0$$

Thus, only if pollution control strategies are substitutes of each other either in terms of cost or marginal damage prevention, cost-minimising level of precaution will unambiguously rise if expected environmental damage increases. If different pollution control strategies are complementary, the change in marginal costs (or marginal expected damage weighted by the probability of being held liable) should not outweigh the marginal change in the liability effect: only if the marginal cost decline less than the liability effect, we can expect a 'normal reaction'.

For the impact of the marginal cost of precaution, we get

$$de_1/dc < 0 \quad \text{if } -f_{1c}(f_{22} + GD_{22}) - [-f_{2c}(f_{12} + D_{12}G - D_2g)] < 0$$

$$\text{hence, } de_1/dc < 0$$

$$\text{if } f_{12}, D_{12} \geq 0$$

or

$$f_{12} < 0 \text{ and } |f_{12}| < |-D_2g|, D_{12} = 0$$

$$D_{12} < 0 \text{ and } |GD_{12}| < |-D_2g|, f_{12} = 0$$

$$de_1/dc < 0 \quad \text{if } -f_{2c}(D_{11}G - 2D_{12}g - D_2g' + f_{11}) - [-f_{1c}(D_{12}G - D_2g + f_{12})] < 0$$

therefore

$$de_1/dc < 0$$

$$\text{if } f_{12}, D_{12} > 0$$

or

$$f_{12} < 0 \text{ and } |f_{12}| < |-D_2g|, D_{12} = 0$$

$$D_{12} < 0 \text{ and } |D_{12}| < |-D_2g|, f_{12} = 0$$

Otherwise, precautionary effort might increase, if cost of carrying out precautionary measures rise.

In conclusion, the previous discussion of the functioning of a negligence rule in a situation of imperfectly observable pollution control activities has shown that, even if

²² The greater or equal to zero sign is supposed to encompass - rather sloppily - the cases: $D_{12}, f_{12} > 0$, $D_{12} > 0, f_{12} = 0$, and $f_{12} > 0, D_{12} = 0$.

the standard of due care is set at the socially optimal level, a variety of distortions and counter-intuitive responses by the polluter to exogenous parameter variations arise. These distortions are not only related to the direct impact of a standard of negligence on the level of observable effort, but also to the induced indirect effects which are caused by changes in marginal profitability of different precaution strategies. Therefore, the environmental policy maker has to look very carefully at the parameters of the model and the characteristics of the initial equilibrium when deciding on an optimal second best policy which might consist of a divergence of the standard of negligence from the socially optimal level²³. Moreover, reactions of the polluter to changes in exogenous parameters like the potential environmental degradation involved or the cost of preventing environmental risk can deviate from the socially optimal response.

3.3 Strict Liability

As long as the polluter is risk neutral, distortions of the kind analysed above do not arise under a strict liability rule. The decision of the court as to whether or not the polluter has to cover the damages caused under a strict liability rule is independent of the level of precaution taken by the polluter. Hence the expected amount of compensatory payments for environmental damages is the crucial variable in the determination of the optimal level of precaution. Under strict liability rule, a risk neutral polluter will choose e_1 and e_2 as to minimise total cost, being the sum of the cost of pollution control and expected liability payments L ,

$$\text{Min } TCS(e_1, e_2) = L(e_1, e_2) + f(e_1, e_2)$$

Restricting the analysis to interior solutions, the first-order conditions for a minimum of the polluter's cost function are given by

$$L_1 + f_1 = 0$$

$$L_2 + f_2 = 0$$

According to his private cost minimisation, the polluter will engage in pollution control activities up to the point where the marginal cost of additional abatement just equals the marginal reduction in expected liability achieved by this extra effort. Thus, as long as compensatory damages are equal to the environmental damages, the polluter will choose the Pareto-optimal combination of pollution control measures. Note that under strict liability, the environmental policy makers and the court need no information whatsoever about the precautionary measures taken. An additional advantage of a strict liability rule is that it does not distort the choice among different strategies of risk reduction. Therefore, if monitoring problems are serious, there is a strong case for a strict liability rule.

²³ The intuition of such a second best policy corresponds to the results derived by Holmström, Milgrom [1991] in the context of multi-task principal agent problems. If tasks are substitutes, there are two ways of inducing higher levels of pollution control. One can either reward this effort type better or decrease the opportunity cost of this activity, by reducing the pay-off to the other activity. If one effort type can not be rewarded, because it is not observable, the only way to induce the agent to engage in this activity is to decrease the incentive for the other activity in the case of substitutes and increase them in the case of complements.

The importance of the distortions generated by a negligence rule compared to strict liability depends (apart from the induced deviation of e_1 , e_2 from their socially optimal level) on the relative effectiveness of the two efforts in environmental risk reduction. When the unobserved effort has a sufficiently high impact on expected environmental damage, a perverse effect on environmental risk generated may occur. If the relative importance of the observable pollution control effort is insubstantial in terms of influencing expected environmental damage, then a negligence rule can incur much higher damages compared to a strict liability rule (case of a dominant damage effect).

So far the polluter has been assumed to be risk neutral. From standard principal-agent theory it is well known that an incentive mechanism as a function solely of observable outcome, is able to achieve the first best solution if the agent is risk neutral. In this case a strict liability rule will be appropriate. When the agent is risk averse, however, he will carry out excessive precaution²⁴. It has been claimed that the polluter could be prevented from doing this, by setting a standard of negligence at the socially optimal level. But this can only be (first best) efficient if all precautionary actions can be observed perfectly by environmental policy makers. When this is not the case, as it is assumed in this paper, there will in general be a Trade-off between providing incentives to take precaution and sharing the environmental risks between polluter and pollutee²⁵. Besides the attitudes toward risk, the choice between the two rules will be influenced by the quality of information on precaution activities and the cost of obtaining this information²⁶. Another solution that is sometimes suggested to the problem of risk aversion are ex ante safety regulations. These are discussed in the next section.

4 Environmental Safety Regulation

In this section, the incentive characteristics of the regulatory approach and the consequences of a combined use of both, ex ante regulation and ex post liability, in environmental policy will be discussed.

Suppose, first, that regulation is the only policy instrument chosen for pollution control. If the environmental policy maker monitors both types of pollution control efforts perfectly, the first best levels of care can be enforced by means of a forcing contract. Any deviation from first best effort levels will be realised immediately and will be

²⁴ If the polluter were risk averse instead, a convex disutility function U (TCS) has to be introduced with $U' < 0$, $U'' > 0$, reflecting increasing marginal disutility of potential losses. Then $U(\text{TCS}) = f(\cdot) + EU(d(e_1, e_2, \theta))$, provided that liability payments do deviate from the environmental damage generated. By Jensen's inequality $U(E(d(\cdot))) < E U(d(\cdot))$. Hence, a risk-averse polluter will carry out excessive precaution. See Holmström [1979], Harris, Raviv [1979] for the issue under which conditions it is favourable to base incentive mechanisms on additional information.

²⁵ Note that suboptimality of a strict liability rule in the presence of risk-aversion, i.e. overprotection cannot be corrected by a negligence rule when substantial monitoring problems are present as it has been shown that even a risk neutral polluter might have incentives to overprotect under an uncertain negligence rules.

²⁶ In the presence of asymmetric information, when the potential polluter is risk averse, excessive precaution cannot be corrected, as it is sometimes suggested, by assuming a perfect insurance market for environmental liability, since any insurance company faces the same moral hazard problem as the environmental policy makers (cf. Shavell [1982]). Here additional problems arise if the interests of the insurance company are not in line with those of the environmental policy maker as there are then two principals and one agent which gives rise to so-called common agency problems.

sanctioned such that the polluter will comply. It is more realistic, however, to suppose that the environmental policy maker will at most be able to observe part of all types of control effort perfectly. Again, the policy maker observes e_1 but not e_2 by assumption²⁷. In the case of perfect observability of e_1 , the polluter will exert no unobservable effort at all when efforts are substitutes, ($f_{12} > 0$). If the environmental policy maker anticipates this; it will set the due care standard such as to minimise

$$TCR = D(e_1, 0) + f(e_1, 0).$$

To offset the negative impact on expected environmental damages when no unobservable effort is exerted, the environmental policy maker will, in anticipation of this behaviour, sets the regulatory environmental standard on the monitored pollution control activities higher than the first-best level. If unobservable pollution control activities are sufficiently important in reducing environmental risk, environmental liability law will outperform this type of regulation. The reason for this is that the incentives to exert an efficient combination of precautionary efforts are even more distorted under an ex ante safety regulation, than under a negligence rule with uncertainty in respect to the findings of negligence. The only case in which no distortion arises, is a strict liability rule.

Hence, in the following, the issue of environmental regulation is addressed in the context of supplementing liability. In reality it can frequently be observed that both policy instruments are used jointly. Whereas in standard environmental economics both instruments are usually regarded as substitutes, in the presence of information asymmetries, they should be used jointly in order to improve efficiency (see for example Shavell [1984], [1987]). Kolstad, Ulen, Johnson [1990] show for the case of one-dimensional precaution that, in the presence of uncertainty the exclusive use of negligence liability may lead to inefficiencies, which can be corrected by adding ex ante regulation. In the following, the joint use of ex ante regulation and different rules of ex post liability will be discussed briefly. Assume, first, that a negligence rule is applied. The question then arises, whether the regulatory standard will affect the definition of due care by the court. If one assumes that the court interprets due care to be fulfilled whenever the regulatory standards are met by the polluter, this excludes any uncertainty in regard to the interpretation of the standard of negligence. The model presented in this paper has shown that, in contrast to conventional wisdom, this might constitute a deterioration in incentives. Regulation eliminates the threat of liability and thereby its useful incentive feature with respect to unobserved effort. If fulfilling the regulatory standard immunises the polluter completely from compensatory damages, the regulation does not supplement but undermines the effectiveness of liability law.

²⁷ Notice that in contrast to the previous discussion it is now assumed that e_1 can be monitored perfectly. This assumption is justified if one considers uncertainty in the findings of negligent behaviour is due to an uncertain court decision and not due to imperfect observability. For the case of monitoring problems giving rise to uncertainty one could, however, argue that safety regulation constitutes an input regulation which involves less noisy observation than the output oriented observation based on observed damages. Assuming perfect observability of e_1 in case of safety regulation, then, is just the extreme assumption with respect to different degrees of uncertainty involved in the two instruments. The discussion related to safety regulation also applies to a certain but incomplete negligence rule or an incomplete negligence rule with perfect observability.

If it is assumed, instead, that environmental policy maker adopts a strict liability rule and, in addition, mandates a certain minimum level of e_i in order to ensure minimum environmental protection²⁸, the potential polluter when implementing the mandatory level is still liable. In this case, it is crucial whether this restriction on e_i is binding. If the mandated level is higher than the one the polluter would choose under strict liability, the consequences depend very much on the interdependencies between effort types. If the two effort types are substitutes, regulation, which improves the incentives of one type of pollution control efforts, aggravates the incentives of the other type, since regulation emphasising the observable effort diverts the polluter's attention away from the unmonitored effort type. Thereby, regulation worsens the incentives for this effort type. In this situation, regulation can actually increase expected environmental damage. Regulation may, however, be effective in reducing expected environmental degradation, when the two efforts are complements. In this case, a higher level of observed action makes it less costly to increase the level of the unobserved action. By the means of this positive reinforcement effect between tasks, a regulation which enforces the level of observed effort to be greater than the unregulated level (i.e. strict liability level), also increases the level of unmonitored effort above the level chosen under strict liability. If the legally required level is lower than the one the polluter would choose according to the analysis of section 3.3, the non-binding regulatory standard should have no effect.

But, even if $e_i < e_i^s$, a non-binding environmental standard can have consequences on pollution control efforts, if the regulatory standard is relevant for the court's decision making on the causal relationship between emissions and the harm suffered. A systematic difficulty of environmental liability is that there is often only a statistical relationship between emissions and damages. The German Environmental Liability Law (Umwelthaftungsgesetz) introduces a reversal of the burden of proof in the case the polluter has not fulfilled the legal standards (which define the so called regular operation of an environmentally risky plant)²⁹. Instead of the victim having to prove causality of the emissions of a specific source, when a suspected polluter has not complied to environmental safety regulation, he has to prove that a particular damage was not caused by his emissions. Hence, as long as the potential polluter complies with the environmental standard, he is, to a large extent, sheltered from being held liable for any occurring damage. This is due to the fact that it will be very difficult, if not impossible, for the pollutee to establish a causal relationship between the damage he suffers and the emissions of a specific source, if the legally prescribed level of pollution control effort has been taken. Thus, if a reversal of the burden of proof is related to a non-binding minimum standard of safeguard, a potential polluter has strong incentives to choose this lower level because he does not have to fear to be held liable.

5 Conclusion and Policy Implications

The discussion of the effects of a negligence rule have shown that, in a situation where imperfect information and multidimensional precautionary activities are considered, a standard of negligence will no longer be able to ensure the socially optimal level of

²⁸ See Schwarze [1993b] for a discussion of different combinations of the two instruments.

²⁹ For a discussion of the procedural aspects see Jost [1993].

precautionary pollution control. This is due to the somewhat more realistic assumption that has been made related to the information requirements of the court, namely, that the model allows for imperfect observability of pollution control activities and, hence, errors in assessing the level of precaution taken. The potential polluter is only partially protected by the negligence rule since, when choosing a certain level of precaution, he is uncertain whether or not he is going to be found negligent by the court. Thus, the potential polluter faces expected liability payments that are smaller than expected environmental damage. This reduces, *ceteris paribus*, the profitability of both types of pollution control. Moreover, the choice with respect to the combination of different pollution control measures will be distorted. Under a negligence rule, incentives for observed effort are enhanced by the effect of observable precaution on the probability of being held liable. Thereby, it is not clear in principle, whether the observed effort level will be higher or lower than the social optimum. The net effect is ambiguous, as there are two offsetting effects. In order to determine the effects on unobservable effort under a negligence rule two cases have to be distinguished. Although, due to the "damage effect", the level of unobservable pollution control will fall compared to the social optimum, the interdependence between the two optimality conditions may generate either offsetting or reinforcing feedback effects. When precautionary measures are substitutes, a sharpened incentive on observed pollution control will lead to a reduction in unobservable effort. If, on the other hand precautionary measures are complements, this second effect would have the opposite direction. It will not be sufficiently strong, however, to offset the first. It might very well turn out that environmental degradation will occur more frequently or more severely under negligence. In particular, if the damage effect dominates the liability effect, effort types are substitutes, and unobservable effort is substantially important in reducing environmental risk exposure in an increase in risk might be experienced. These distorting effects prevail to an even larger extent if an *ex ante* safety regulation is chosen.

If the set of possible strategies in reducing environmental risks is somewhat richer than just a one-dimensional decision, the fact that there might be uncertainty involved in verifying negligent behaviour may lead to an improvement in incentives compared to a certain standard of due care or an *ex ante* safety regulation. The crucial feature of an uncertain legal standard is that an element of strict liability enters the liability rule: even if the polluter takes a very high level of (observable) precaution, he still faces the risk of being held liable. Thus, the fact the standard of due care is open to an uncertain interpretation of the evidence by the court or that precautionary efforts are only imperfectly observable is not entirely detrimental in a world of multi-dimensional precaution and limited observability.

Comparative static analysis has shown that the response of the polluter under a negligence rule may deviate from what one would usually expect, i.e. an increase in the standard of due care may lead to a decrease in the level of precaution taken by the polluter. Likewise, an increase in potential environmental damage will not necessarily lead to higher efforts in pollution control and an increase in the cost of precaution will not, in any case, lead to a decline in the cost-minimising level of pollution control. Therefore, the environmental policy maker has to look very carefully at the parameters of the model, when deciding on an optimal second-best policy consisting of a divergence of the standard of negligence from the socially optimal level. Moreover, a

negligence rule will always cause some distortion in the choice of combinations of different effort types compared to a strict liability rule. In the model presented in this paper, first-best results are only achieved under strict liability. This result is, however, highly sensitive in regard to the attitude towards risk of the potential polluter. If the polluter is risk averse, he will carry out excessive precaution which causes a deviation from the social optimum. The optimal risk allocation cannot be re-established by implementing a negligence rule. The reason for is the distortion that is induced in a situation where the polluter is better informed about the precautionary measures that have been carried out.

6 References

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