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Efficiency and applicability of economic concepts dealing with environmental uncertainty: A critical analysis

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Abstract

The aim of the paper is to develop evaluation criteria that enables one to analyse the efficiency and applicability of economic concepts dealing with the problem of environmental uncertainty; and to apply these criteria to some of the existing concepts. In order to analyse the applicability of the concepts, environmental uncertainty is divided according to different criteria (for example, the causes for uncertainty). With such a structure, one can show that while the economic concepts are able to deal with some types of environmental uncertainty quite well, they are unable to deal with others adequately. The analysis on efficiency distinguishes between environmental risk and ignorance. Risk describes a situation where scientists are able to attribute probabilities to a variety of outcomes. Ignorance exists when the effects of human activities on the environment are not all known. The evaluation criteria will be applied to analyse the efficiency and applicability of liability, the concept of a risk premium developed by Siebert, the environmental assurance bonding system proposed by Costanza and Perrings as well as the policy recommendation to promote integrated technologies. The analysis shows the following important results: (I) The application possibilities of the four concepts differ significantly. (II) A concept which concentrates on the reduction of risk may lead to an increase in ignorance. (III) While an economic concept may be efficient in the context of risk, it can be inefficient when ignorance exists. (IV) A trade-off exists between the possibility to precisely state whether an economic concept is efficient and the scope of its applicability.

Keywords: Environmental uncertainty, environmental risk, liability, integrated technologies, environmental bonds

JEL-classification: Q2

The criteria for the second division of environmental uncertainty is the extent of knowledge on the consequences of human intervention into nature. Following Knight (1921) a distinction between risk and uncertainty is often made in economic theory. „The practical difference between the two categories, risk and uncertainty, is that in the former the distribution of the outcome in a group of instances is known (either through calculation a priori or from statistics of past experience), while in the case of uncertainty this is not true, the reason being in general that it is impossible to form a group of instances, because the situation dealt with is in a high degree unique“ (Knight 1921, p.233). Similar to Knight's distinction, environmental uncertainty shall be divided into „risk“ and „ignorance“[2]. Risk exists when it is possible to attribute - more or less exactly - probabilities to various environmental damages that might occur. An example of environmental risk is the greenhouse effect. There is a scientific consensus that the emissions of gases like carbon dioxide contribute to global warming, yet the extent is unclear. However, scientists seem to be able to attribute probabilities to the various temperature increases that a rise of the carbon dioxide-concentration in the atmosphere will cause. In a situation of ignorance not all outcomes are known. Consequently, an emission might be unknowingly harmful. For example, ignorance existed with regard to CFC before it was discovered that CFC destroys the ozone layer. The example of CFC shows that mankind can never foresee all the damaging effects of an emission. In other words, ignorance exists in all human interventions into nature.

Obviously, the division in ignorance and risk is too strict to allow all relevant cases in the real world to be attributed to one of the subdivisions. The example of CFC represents rather the extreme limit of a continuum between ignorance and risk. More likely, scientific knowledge will allow some speculation in what ways an emission might be dangerous. This speculation can provide a starting point for scientific research. With the results of this research, it might be possible to assign - more or less accurately - probabilities to the different damages that may be caused by the emission. This would suggest, that a movement from ignorance to risk often takes place. Despite these qualifications, the categories of risk and ignorance seem to offer a useful basis for the evaluation of different nuances of environmental uncertainty that exist in reality.

The third division of environmental uncertainty is orientated towards the number of polluters. In some cases, a high number of polluters contributes to an emission which has uncertain

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[2] „Environmental uncertainty“ is used in the literature as a generic term. The term „environmental ignorance“, which is borrowed from Faber and Proops (1993), seems more appropriate despite the terminology coined by Knight.

effects on the environment. This uncertainty shall be called "uncertainty caused by many polluters ". In other cases, the emission stems only from one or a few polluters and shall be called "uncertainty caused by a few polluters". An example of the former type of uncertainty is the greenhouse effect, an example of the latter type is a medicine which is produced by only a few companies and has unforeseen side effects like thalidomide. Table 1 shows an overview of the different types of environmental uncertainty.

criterion of division	different types of environmental uncertainty				
behaviour of emissions in the environment	*damage uncertainty*	*synergy uncertainty*	*accu-mulation uncertainty*	*diffusion uncertainty in space*	*diffusion uncertainty over time*
extent of knowledge	*risk*			*ignorance*	
number of polluters	*uncertainty caused by the emissions of many polluters*			*uncertainty caused by the emissions of a few polluters*	

Table 1: Types of environmental uncertainty

It should be noted that different forms of uncertainty can coexist. For example, a certain emission has damaging effects which are not yet known. The place of the emission and the place of the damage are far apart, the damage only occurs when the emission interacts with another emission and the emission stems from many polluters. We have at the same time ignorance, diffusion uncertainty in space, synergy uncertainty and uncertainty caused by many polluters.

2.2 Efficiency in the context of environmental uncertainty

In order to define efficiency in the context of environmental uncertainty, it is necessary to determine the emissions which environmental policy should concentrate. Let us first consider a world of certainty where it is assumed that if an emission is harmful, this is known. Here, environmental policy should concentrate on those emissions which cause harm. The reduction of other emissions is costly but does not reap any benefits, and should therefore be avoided. The situation is similar in a world of risk, where, if there is uncertainty on the damaging properties of emissions, it is still possible to attribute probabilities to the various environmental damages that may occur. Environmental policy should concentrate on those emissions, the reduction of other emissions is again undesirable. The situation is different in a world of ignorance. Here, we accept the fact that we do not know whether emissions are harmful. Therefore, environmental policy should take into account all emissions as every emission has a potential to cause harm.

If environmental policy considers all potentially harmful emissions the following questions arise: Which emissions should preferably be reduced to decrease the risk of environmental damage most effectively? Should all emissions be equally reduced or should there be a preference to reduce some emissions more than others? And secondly, can the increase of one potentially harmful emission be offset by the reduction of another potentially harmful emission? The first question may be answered by making the common assumption that the first derivative of the marginal damage function is positive. Although there is ignorance, it seems acceptable to make this assumption because experience has shown that it is valid for most emissions. Given that there is no other information, a plausible conclusion from this assumption is that it is efficient to reduce those substances, that are most being emitted, because this will lead to the highest damage reduction. However, to follow this recommendation, there must be a common measurement that tells us which emission is being emitted most. A measurement „quantity of an emission" is not suitable as the effects of two harmful substances, which are being emitted in the same quantity may differ completely. Another possible measurement is the relative change in the natural background concentration of a substance. Here again, an x-percent change in the natural background concentration of two emissions may have completely different effects. As there is no common measurement, the assumption that the first derivative of the marginal damage function is positive does not help to recommend which emissions to reduce first. To conclude, there does not seem to be an analytical tool to compare the effects of different emissions in the presence of ignorance. Therefore, it is not possible to recommend the order in which different emissions should be reduced. The lack of an analytical tool does also not allow one to say that a reduction of one emission can be offset by an increase of another emission. The only clear statement that can be made is that in a world of ignorance, the danger of environmental damage decreases when at least one emission is reduced and no other emission increases[3].

After having determined which emissions are relevant in the different contexts of certainty, risk and ignorance, it is now possible to analyse the meaning of efficiency in the presence of environmental uncertainty. Following Baumol and Oates (1971), efficiency is secured when an economic concept leads to the least-cost implementation of abatement activities to obtain a given standard. In a world of certainty, this is achieved when the marginal cost of reducing an emission is equalised across all activities. We do not need to be concerned with substitution of regulated emissions by other emissions. The standard setting body is informed about possible

[3] The analogy to the Pareto-criterion is obvious. It is assumed that we cannot measure, and therefore compare, the utility of individuals. A situation is only Pareto-optimal when at least one individual is better and none worse off.

damages and can regulate the other emissions if it wishes to do so. The same holds in a world of risk. While the existence of risk might have been taken into account by the determination of the standard (see Siebert 1987a and for different aspects of the decision problem on the amount of pollution in a world of uncertainty Ayres and Sandylia, 1987, Drepper and Mansson, 1993, Faucheux and Froger, 1995 and Wätzold, 1998, chapter 3), it does not affect the optimal allocation of abatement activities.

In a world of ignorance, environmental policy must not only consider one emission, but all emissions. However, it seems impossible that a regulatory body is able to regulate all existing emissions. Therefore, the efficiency analysis has to take into account the effects of a standard on one emission on other emissions too. More precisely, it must be considered that a standard on one emission might lead to a substitution of this emission by other potentially harmful emissions. Or, in a more favourable situation, the standard on one emission might lead to a reduction of other emissions as well. In order to see that these effects have an influence on the efficiency of abatement activities, it is assumed, for a moment, that all the relevant marginal damage costs are known. Then, the efficiency analysis must not only consider the different marginal abatement costs to reduce the targeted emission but also the marginal increases or reductions of the costs that are caused by changes of other emissions. The least cost implementation of abatement activities is then achieved when the marginal costs of reducing the targeted emission plus the additional marginal damage costs or costs saving are equalised across all activities. However, in a world of ignorance, the different marginal damage costs of potentially harmful emissions are not known. Therefore, there is no possibility to say whether abatement activities are efficient or not. Yet, the above reflections make clear that conditions for least cost implementation of environmental policy in a world of ignorance are different from those in a world of risk and certainty.

3. Economic concepts dealing with environmental uncertainty

3.1 Risk premium

The concept of a risk premium can be derived from a model by Siebert (1987, chapter 14) on the optimal environmental quality in a world of uncertainty. In essence, the concept says that if one is uncertain about the damage of an emission, a „risk premium“ (Heller 1989, p.189) should be added to the expected damage to reflect this uncertainty[4]. This means an additional factor is taken into account on the cost-side in a cost-benefit-calculation. Siebert's model is

[4] Another form of risk premium would be the quasi-option value (Arrow and Fisher, 1974), see Wätzold, 1998 for an assessment with respect to efficiency and applicability.

based on previous chapters of his book where he determines the optimal environmental quality in a static as well as in a dynamic setting and in a world of certainty. Uncertainty is introduced into the model by assuming that „variables strategic to the problem of environmental allocation such as assimilative capacity, the stock of accumulated pollutants or environmental quality in a given moment of time diverge from a mean on both sides with the mean being defined as the expected value of the mathematical variance of possible results“ (Siebert 1987, p.221). The main features of the model are as follows: The environmental quality U

$$U=N(S,\tilde{\theta})$$

becomes a random variable depending on the stock of pollutants S and on states of nature $\tilde{\theta}$. Social welfare W depends on environmental quality U and a private good Q. The welfare function is assumed to be well behaved.

$$W=W(Q,U)$$

Γ denotes a utility function indicating risk attitudes of society. The expected utility of social welfare in any given period is

$$E\Gamma\ (W(Q,U)).$$

The „policy maker“ maximises the present value of expected utility over time. Welfare for the planning period $[0,\infty]$ is discounted with a strictly positive discount rate ($\delta > 0$)[5].

$$\int_0^\infty e^{-\delta t}\{E\Gamma(W(X,N))\}dt$$

The policy maker is risk averse if $\Gamma'>0$ and $\Gamma''<0$. One result of the model is to show the policy implications of an increase in risk, for instance, by a mean preserving spread with more weights in the tails of the distribution. Under the assumption that the policy maker is especially risk averse, a mean preserving spread implies a higher expected marginal disutility of welfare from pollution. This, in turn, leads to a lower level of pollution. We can therefore derive the following policy implication from the model: the level of pollution should be lower in a situation of uncertainty compared to a situation of certainty; and an increase in uncertainty should lead to a decrease in pollution.

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[5] The maximisation problem is solved by using control theory. The equation of motion represents the change in accumulated quantities of pollutants. The constraints consists of an emission function, a production function, an abatement function, a diffusion function and a damage function, see Siebert (1987a, S.204f.).

In assessing the applicability of the concept, the distinction between risk and ignorance is relevant. The structure of environmental uncertainty in Siebert's model is the structure of risk. Therefore, the policy recommendation of a risk premium can only be applied in a world of risk and not in a world of ignorance. This conclusion may be rejected by arguing that the way of modelling does not preclude the applicability of the model in a world of ignorance. The author accepts that this argument may be given some weight. However, if one accepts this argument, the next question is the level of pollution a policy maker should aim for in a world of ignorance. It seems that this question cannot be answered within the framework of the model. For this reason and for the reason that many people certainly advocate a restriction of environmental policy on risk, it will be assumed, that the concept of the risk premium can only be applied in a world of environmental risk. It is important to note that despite its limited scope of applicability, the concept may also have effects on environmental ignorance. As the policy is only targeted at emissions which are dangerous in a world of risk, but not at those which are dangerous in a world of ignorance, polluters have an incentive to substitute the former emissions by the latter ones. In assessing the importance of this aspect, one should bear in mind that the options available to substitute certain emissions by others may, in some cases, be limited by sunk costs and path dependency of existing technologies. The other subdivisions of environmental uncertainty are not relevant here. Apart from ignorance, the concept of the risk premium can be applied in all cases.

Efficiency in a world of risk depends on the economic instrument applied to achieve the pollution reduction. The assessment is the same as in a world of certainty and extensively discussed in the literature (see e.g. Baumol and Oates 1988). However, as there is an incentive to substitute regulated emissions by unregulated ones, the assessment of efficiency is different when we take ignorance into account. Abatement activities that are efficient in a world of risk may well be inefficient when they lead to an increase in potentially harmful emissions. Although this substitution clearly bears the danger of inefficiency, as pointed out above, we do not know in a world of ignorance whether an abatement activity is efficient or not.

3.2 Promotion of integrated technologies

The concept to promote integrated technologies has been developed in the context of the idea of preventive environmental policy. The basic idea of preventive environmental policy is to identify environmental problems in a very early state and to analyse the preconditions for environmental goals, policies and institutions that lead to the long-term protection and regeneration of the natural environment (Simonis, 1988, p.8). In this framework varies policy approaches have been suggested (for an overview, see Simonis 1988), the promotion of integrated technologies being the most prominent one (Walter 1989, Zimmermann et al. 1990).

In the literature on the promotion of integrated technologies, a distinction between end-of-pipe and integrated technologies is made. End-of-pipe technologies do not change the original production process, they are added to it. Examples of end-of-pipe technologies are the conventional sewage treatment technologies. In general, emission are reduced by using a filter. Typically, an end-of-pipe technology leads to the reduction of only one emission. All other emissions increase or remain on the same level. The reason is that the construction and the operation of the technology need material and energy that is additional to those being used for the construction of the original production plant. More importantly, the filtering process often leads to residuals with unknown toxicity. Furthermore, energy and material are again needed for the disposal of these residuals. The increase of emissions other than the filtered one obviously bears the danger of an increase in environmental uncertainty. Integrated technologies change the production process itself. An example is the recycling and reuse of acids in the pickling process of steel. This leads to the avoidance of residuals. Typically, the targeted emission is not the only one that is reduced but other emissions are reduced as well. Furthermore, no other emission is increased. From the point of view of environmental uncertainty, integrated technologies are valued more positively. The amount of material and energy needed for the construction of the technology is usually less than that needed for the construction of an end-of-pipe technology as the production process is only altered but not enlarged. Furthermore, there is no residual which has to be disposed. As all emissions are reduced and no emission is increased, integrated technologies lead to a reduction of environmental uncertainty. The definition of integrated and end-of-pipe technologies is targeted towards the analysis of environmental uncertainty. In reality, probably very few technologies are integrated technologies as defined here. Despite these reservations, the strict definition seems useful as it provides a basis to evaluate the varies combinations of these technologies with respect to environmental uncertainty.

As integrated technologies are more suitable in a world of environmental uncertainty, two questions arise: What are the incentives that influence the choice of firms between the two different technologies in a pure market setting? And how are environmental policy instruments evaluated with respect to the technology choice? Only a brief survey of the main results will be given as the analysis itself is not of interest for the purpose of this paper (see for more detailed analysis Walter, 1989, Hartje, 1990, Kemp, 1993 and for a summary Wätzold, 1998, chapter 5). At first glance, one might expect integrated technologies to dominate as their material and energy savings lead to lower costs. However, Ryll (1990, p.94) estimated that in Germany 80% of all environmental technologies were end-of-pipe technologies in the 1980s. This contradiction is explained by Hartje (1990) who shows that in a pure market setting, there are more incentives to choose end-of-pipe technologies than integrated technologies. For example, there is a strong bias toward end-of-pipe technologies when old plants have to reduce their emissions. Then, the purchasing costs tend to be higher for integrated technologies than for end-of-pipe technologies. By choosing an integrated technology, the production plant has to be renewed completely or at least parts of it. Often, the old plant cannot be sold which means that sunk costs exist. By contrast, an end-of-pipe technology does not in general require a different production plant as it is only added to the original production process. Considering the existence of sunk costs, an end-of-pipe technology may well be chosen, even if a new production plant including an integrated technology is less expensive than a new conventional production plant plus an end-of-pipe technology. Furthermore, the costs of alteration tend to be lower for end-of-pipe technologies than for integrated technologies. In general, an integrated technology leads to a change in the production process itself with the consequence of learning costs and training of workers. An end-of-pipe technology also leads to learning costs and training costs for workers. But this is only for the technology itself as the production process remains unchanged. Therefore, Hartje (1990, p.150) estimates that the learning and training costs for end-of-pipe technologies are lower than those for integrated technologies.

Walter (1989) suggests that end-of-pipe technologies have become the dominant technological design. Because of sunk costs, integrated technologies might not be chosen even if they are less costly than end-of-pipe technologies in a situation without sunk costs. The dominance of end-of-pipe technologies leads to the question on the type of the environmental policy instrument which can lead to an increase in integrated technologies. A standard seems to be less favourable for integrated technologies than a system of tradable permits, which in turn is less favourable than an eco-tax (Walter, 1989). The disadvantage of an emission standard is that it is usually oriented at the existing abatement technologies. As they are mainly end-of-pipe technologies these technologies provide „the model" for environmental legislation and by this their dominance is reinforced. An important criterion for the technology choice is the time which is allowed to adjust the emissions of a plant to the reduction target. If a standard is very strict in this respect, firms have to reduce the emissions of their old plants. However, this favours end-of-pipe technologies because of sunk costs. By contrast, economic instruments allow firms a choice between emission reduction and payment of tax or the use of tradable permits. However, in the case of tradable permits, a temporarily high price for the permit can also force a firm to buy an abatement technology. Walter (1989) believes that none of these instruments provide enough incentives to lead to a switch from end-of-pipe to integrated technologies. He proposes that in addition to these instruments, the government should subsidise the research and development of integrated technologies.

The concept to promote integrated technologies is applicable to environmental risk as well as ignorance. However, the concept is more targeted towards ignorance. The main aim is not to concentrate on one emission, where environmental risk exists, but to reduce a broad spectrum of emissions. The other subdivisions of environmental uncertainty are not relevant here as through the general reduction of emissions, all sorts of environmental uncertainty are reduced.

Efficiency will be examined by assuming that the policy maker uses an economic instrument to reduce one emission where environmental risk exists. In addition, the subsidies for integrated technologies will be considered. If an economic instrument leads to the use of integrated technologies by the firms in a world of risk there is no doubt that the least-cost-implementation of abatement activities is achieved. The case is different when only a subsidy induces firms to use an integrated technology. Here, it is not possible to clearly state whether efficient abatement activities are being undertaken. If one believes that despite sunk costs, firms will make the right technology decisions the subsidy leads to inefficient behaviour. An end-of-pipe technology will be less costly to reduce the emission, consequently, the subsidy leads to inefficient abatement activities. However, if one believes that the dominance of a technological design can lead to an inefficient technology choice, subsidies may be efficient. However, it remains unclear to what extent subsidies are justifiable. In a world of ignorance, it must be emphasised that the possibly inefficient substitution of regulated emissions by potentially harmful emissions is not possible. Integrated technologies do not lead to an increase in other emissions but lead to an overall reduction of emissions. If the economic instrument leads to the use of integrated technologies, it is again evident that the least-cost-implementation is achieved. If a subsidy is needed to make the integrated technology profitable for the firm, this is not necessarily inefficient, even if one believes that despite sunk costs, the firm will make the right technology decision. The reason is that higher abatement costs may be offset by a reduction in potentially harmful emissions. However, as the benefits of the reduction of potentially harmful emissions are unknown, it is impossible to say whether or not subsidies lead to efficient abatement activities.

3.3 Liability

This chapter examines the role liability can play with respect to environmental uncertainty. It draws on the analysis common in law and economics literature which stresses the deterrent aspects of liability. The focus is therefore on the question whether appropriate incentives that induce the polluters to behave efficiently are created. Firstly, how liability basically functions is examined in the context of a simple model commonly used in law and economics literature (see among others Schwarze, 1996). Secondly, to gain a better understanding of how liability functions in reality some difficulties that arise upon the lifting of a few assumptions of the model are discussed. The analysis is restricted to the case where polluters' behaviour affects damage risks but pollutees' behaviour does not, since this seems to be the relevant case for environmental uncertainty (Wätzold, 1998). It is also limited to strict liability (polluters must pay for all damages that they cause) as this is considered the most suitable rule for environmental uncertainty (Panther, 1992, Wätzold, 1998).

The main features of the model are as follows: There exists one polluter which pursues an activity which causes, with a certain probability, a damage to a pollutee. The polluter is able to exercise different levels of care that lead to different levels of expected damages. All relevant participants (polluter, pollutee, courts) have free access to all information. The actual damage and the compensation received are identical. This implies, that all damages can be expressed in monetary terms and the ability of the polluter to fully compensate the pollutee. The identification of the polluter of a damage and the assignment of the damage to a pollutee is possible and involves no costs. Furthermore, litigation is free.

The socially efficient level of care is achieved when the total costs for society are minimised. This is the sum of the costs for exercising care plus the damage costs. Under strict liability, the polluter must not only pay for its costs of exercising care but also for all the damage that it causes. Hence, polluter's total costs are equal to the total costs for society; and because it will seek to minimise its total costs, polluter's behaviour will lead to cost minimisation for society as well. This result has been achieved by using unrealistic assumptions. A better picture of how strict liability functions in reality may be gained, when some of the assumptions are lifted. It can be shown that the expected damage and the compensation, which the polluter can expect to pay, differ, thus, creating incentives to move away from the efficient level of care. The main reasons why liability does not perfectly work in the real world are the following: the fact that the actual damage exceeds available compensation, difficulties in expressing the value of environmental damages in monetary terms, no association of damage with private property, difficulties of proving causation and high costs of law suits. (see, for example Shavell, 1987, Dewees, 1992, Panther, 1992 and Schwarze, 1996).

As the value of the polluter's property which may be seized by an execution order is limited, it is possible that actual damage may exceed the compensation which the polluter is able to pay. This discrepancy may provide an incentive for the polluter to deviate from the efficient level of care. A mandatory public liability insurance ensures that there is enough money available for compensation. However, insurances are also prone to inefficiencies as information asymmetries between the insurer and the insured give rise to moral hazard problems. While considerable advances have been made over the last years to improve tools to express the value of environmental damage in monetary terms, it is still impossible to adequately measure some damage, e.g. damages to human lives and species extinction. Therefore, if it is impossible to express the damage in monetary terms, the compensation and the damage cannot be equivalent. Another obstacle for the use of liability in cases involving environmental damage is the fact that environmental damage is often not associated with private property. This damage is not protected by liability as there is no plaintiff which can claim that it has suffered a loss (Dewees, 1992, p.451).

A major barrier to success in claims for problems associated with environmental damages is the difficulty of proving causation. In order to be successful a plaintiff must prove that he has suffered actual damage, that the damage is caused by a specific pollutant, that the pollutant is of a type discharged by the defendant, and that this pollutant arose from the defendant and not from some other polluter. The typical case where these requirements are probably fulfilled is an isolated factory discharging a concentrated waste that causes a unique form of harm (Dewees, 1992, p.451). In other cases, the chances of a successful claim are much lower. Some developments have helped to lessen the burden of proving causation. In situations where it is possible to attribute probabilities to the causation, it has been proposed that the polluter should be held liable in proportion to its probability of causation (proportionate liability). For example, if it is possible to prove that a polluter increases the lung cancer rate by 100%, the polluter should be liable for 50% of the overall damage caused by lung cancer. As the polluter is confronted with the damage that is caused by it, it has an incentive to achieve the optimal level of care (Shavell, 1987, pp.116-126). Joint and several liability has been applied when a single polluter cannot be identified and the harm is single and indivisible. It makes each successfully sued defendant potentially liable for an amount up to the entire damage caused, regardless of the size of its individual contribution. The defendant can, in turn, get reimbursement from the other polluters. While joint and several liability undoubtedly makes it easier for the pollutee to be compensated, it does not necessarily induce efficient levels of care. The reason is that it might be difficult for the defendant to receive sufficient payments from other polluters (Tietenberg 1989, Dewees 1992). Joint and several liability cannot be applied when the number of polluters is very high and each polluter causes only a small proportion of the damage. In such a situation one polluter would probably not be able to pay a significant contribution of the whole damage and it would also not be able to get reimbursement from the other polluters.

Litigation is not free. Often, environmental damage imposes small costs on a large number of people. It is not worthwhile for the individual to pursue litigation as the costs involved are much higher than the damage which has been occurred. One solution to this problem is the aggregation of claims, most commonly achieved in the United States by the class action lawsuit. However, there are also problems with this solution. Damages caused to different members of the class arise at different times and widely vary in severity. There are also substantial costs associated with identifying the class and the distribution of the proceeds in a successful claim (Dewees, 1992, p.451). Even if the number of injured is relatively small, costs for litigation are substantial. For example, it has been estimated that, considering all tort cases in the USA, plaintiffs retain only 46% of total litigation expenditures as compensation (Kakalik and Pace, 1986). To sum up, liability does not work in the desired way, when some of the assumptions of the basic model are lifted. However, it is possible to identify some areas where liability seems to work reasonably well and others where this is not the case. It has to be examined to which areas the different types of environmental uncertainty belong to.

The structure of environmental risk allows the application of proportionate liability. In a world of ignorance litigation is not possible if the causation between polluter and pollutee is unknown. However, the existence of liability has indirect repercussions on the polluter's behaviour. It has to consider that environmental research transforms the world of ignorance in a world of risk or certainty where a polluter can be sued. Damage uncertainty does not lead to particular difficulties for the application of liability. In the case of synergy uncertainty, as different polluters are responsible for the damage, this may lead to difficulties in proving causation. Diffusion uncertainty in space can give rise to higher litigation costs as there may be a significant physical distance between the plaintiff and the defendant. A different problem is involved with diffusion uncertainty over time. As the causation is discovered after the emission took place, it is possible that the polluter does not exist anymore. A mandatory public liability insurance might mitigate this problem but it does not solve it completely as the duration of the insurance policy is limited. A similar problem may arise with accumulation uncertainty if the accumulation period is long enough. There is also a risk that at least a significant number of polluters no longer exists by the time the damage is discovered. The ideal situation for litigation is where there is only one polluter. When uncertainty is caused by a few polluters, the application of joint and several liability and - if possible - proportionate liability, does mitigate difficulties of proving causation. However, litigation is not feasible if the pollution is caused by many polluters because it is not possible to prove causation or the costs of doing so are too high.

The efficiency analysis of liability differs from the efficiency analysis of the other two concepts as there is no standard setting body. In the context of liability, the optimal level of care is chosen by the polluter itself. Nevertheless, the analysis of the optimal level of care presented above offers a tool to analyse the efficiency of liability. In a world of risk, the analysis is the same as the efficiency analysis which has been presented above. The reason is the possibility to attribute probabilities to damages in a world of risk, that is the possible damage can be expressed as expected damage. From the analysis above, we know that in such a case liability leads to efficient levels of care in the context of the basic model and to inefficiencies once a more realistic perspective is adopted. As we do not know all damages in a world of ignorance, the analysis cannot be applied. However, the polluter may be held responsible for the whole damage that exists or parts of it, once ignorance is transformed into risk or certainty. The incentive to substitute emissions of which the damage is known by potentially harmful emissions is therefore reduced compared to a situation where the polluter is not responsible for compensation.

3.4 Environmental Bonds

Perrings (1989) and Costanza and Perrings (1990) have proposed that environmental bonds should be used when the environmental impact of an innovative activity is not known[6]. The basic idea is that a bond, which is equivalent to the current best estimate of the largest potential future environmental damages, is levied. The bond plus part of the interest is returned if the polluter proves that the suspected damages has not occurred or will not occur. If damages do occur the bond will be forfeited to a corresponding amount. The part of the interest that is not returned to the polluter will be used to finance the administration necessary for the environmental bonding system and research on environmental pollution control technology and management (Costanza and Perrings, 1990, p.69). The decision process on how to determine the size of the bond follows Shackle's decision theory (see, for example, Costanza and Perrings, 1990, p.67 and Shackle, 1958). It is applicable in situations where the range and

[6] For a critical assessment of bonds see Shogren et al., 1993.

probability distribution of the future effects of present actions are unknown. In such circumstances, there may be a number of outcomes which will draw the decision-maker's attention and not cause surprise if they do occur, but there is no basis to calculate the probability of their occurring. The decision-maker will focus on those positive or negative attention-catching outcomes to which it attaches the lowest level of disbelief. These are the focus losses and focus gains of the action. The conjectured worst case outcome recommended as the basis of the bonds will be the focus loss of the activity. „It is not, therefore, the worst case 'imaginable', but the least unbelievable of those costs of an activity to which the decision-maker's attention has been drawn for whatever reason - publicity or public sentiment included (Costanza and Perrings, 1990, p.67)". Institutionally, the bonds are determined by an environmental regulatory agency with the assistance from an "independent scientific advisory board consisting of independent environmental experts" (Costanza and Perrings, 1990, p.68). Costanza and Perrings leave it unclear whether the polluter has a right to appeal against the decision of the environmental regulatory agency. If the polluter is barred from having a right to appeal, a risk of irreversible arbitrary decisions exist. If a right to appeal is accepted, one has to find procedures to evaluate the decisions of the independent advisory board. This is difficult as the decision-making process, according to Shackle's theory, is highly subjective.

The general applicability of environmental bonds is restricted by phenomena that also hamper the application of liability rules. These include difficulties in expressing the value of environmental damages in monetary terms, problems of proving causation and the possibility that the actual damage exceeds the value of the bonds although the probability of the occurrence of the last mentioned phenomenon seems rather small. Costanza and Perrings (1990, p.65) restrict the use of environmental bonds to cases where the data do not exist to compute an expected value for the future environmental costs of current activities. For cases where sufficient data exists, they propose that the polluter should commercially insure against future environmental damage. In other words, environmental bonds are not recommended in a world of risk. They are also not applicable in a world of ignorance. In order to influence the decision-making process in the context of Shackle's theory, the attention of the decision-maker must be drawn to the outcome. This is not necessarily the case in a world of ignorance. However, while not being directly applicable, environmental bonds influence decisions in a world of ignorance. They are applicable in the area between risk and ignorance when there is some suspicion that an emission has certain damaging properties. This possibility of application means that the polluter has to take into account the possibility that an emission is harmful and a bond will be levied. In the case of diffusion uncertainty over time, there is a risk that the damage is not discovered before the bond is returned. In a world of uncertainty, the decision maker does not necessarily know the moment when the damage becomes visible. The same applies to accumulation uncertainty. If the decision-maker estimates that the damage will occur too early it may return the bonds although there will be damage later. Environmental bonds can only be applied when the number of polluters is relatively low. Administrative costs of collecting the bonds, surveying the polluters, keeping track of them and finally returning the money or parts of it may quickly rise to unacceptable levels in situations where the number of polluters is too high.

The efficiency analysis of bonds is similar to that of liability. Ideally, bonds induce an efficient behaviour as the polluter is confronted with the costs caused by its emissions. In a more realistic perspective, the same aspects that hamper the applicability of bonds also lead to inefficiencies as they decrease the possibility that the polluter is confronted with the complete damage. Furthermore, an efficiency analysis must ask whether the orientation of the bond on the focus loss is efficient. This is not the case for two reasons. Firstly, the determination of the size of the bond is highly subjective and not related to efficiency considerations. Secondly, the focus loss is only one out of many possible different outcomes and the neglect of other outcomes leads to inefficiency. However, this argument has to be qualified. The amount that the polluter has to pay in the end is calculated according to the actual damage and not the focus loss. Therefore, the neglect of outcomes other than the focus loss is only inefficient as the size of the bond determines the interest and not all the interest is returned to the polluter. Furthermore, it is difficult to find an efficient decision rule which guaranties that the polluter will pay for the damage till the limit of the bond. In the context of the efficiency analysis, it is important to note that the substitution of regulated by unregulated emissions in a world of ignorance may only arise to a limited extent. The possibility of future payments for environmental damage may often prevent substitution.

4. Results and conclusion

I will now summarise the main results and show that a trade-off exists between the possibility to precisely state whether an economic concept is efficient and the scope of its applicability.

Environmental uncertainty	economic concepts			
	risk premium	promotion of int. technol.	liability	environmental bonds
damage uncertainty	++	++	++	++
synergy uncertainty	++	++	+	+
accumulation uncertainty	++	++	+	+
diffusion uncertainty in space	++	++	+	++
diffusion uncertainty over time	++	++	+	+
ignorance	-	++	+	+
risk	++	+	++	0
uncertainty caused by the emissions of many polluters	++	++	0	0
uncertainty caused by the emissions of a few polluters	++	++	++	++
economic concept: ++ is applicable without problems; + is applicable with problems; 0 is not applicable or shall not be applied; - increases this sort of uncertainty				

Table 2: Overview of the applicability of the different economic concepts

The overview given in table 2 shows that the application possibilities of the four concepts differ significantly. The division according to the different behaviour of emissions in the natural environment is important with respect to liability and environmental bonds. In cases other than the damage uncertainty, the application of both or one concept is not without difficulties. Interesting results can be derived from the distinction in risk and ignorance. Obviously, with the exception of preventive policy, all concepts can be applied with less problems in a world of risk. The result that a concentration on risk leads to an increase in ignorance has to be strongly emphasised as it is policy relevant. In many countries, a great deal of environmental policy is targeted towards risks, but ignores that this might lead to a substitution by potentially dangerous substances.

The efficiency of the risk premium in a world of risk depends on the policy instrument. In a world of ignorance, it has to be taken into account that there is an incentive to substitute regulated emissions by non-regulated ones which bears the risk of inefficiency. While in the context of the promotion of integrated technologies this substitution does not take place, it cannot always be determined whether policy measures undertaken in the context of environmental policy are efficient or not. Liability is most efficient in a world which consists of risk, one polluter, one pollutee and damage uncertainty. The less these feature exist, the less are the incentives for efficient levels of care. Beside aspects that lower the probability that the polluter must pay for the damage, the efficiency of environmental bonds is weakened by the orientation on the focus loss. However, both policy instruments do not encourage substitution of regulated by unregulated emissions.

In combining the results of the efficiency and applicability analysis, one can derive an interesting result. A trade-off exists between the possibility to precisely state whether an economic concept is efficient and the scope of its applicability. Where a concept can be applied to many different types of uncertainty, as in the case of the promotion of integrated technologies, precise statements of the efficiency of a concept are not possible. Whereas, where it is possible to clearly state that a concept leads to efficient or inefficient abatement activities, the scope of its applicability is rather narrow. The reason for this trade-off is the impossibility to make precise statements on efficiency in a world of ignorance. If the policy aim is to broaden the scope of environmental policy and to include the reduction of ignorance, an efficiency analysis cannot deliver those precise results known from the efficiency analysis in a world of risk or certainty. The consequence of this is the possibility of inefficient abatement activities. This can be interpreted as the price which has to be paid in order to reduce environmental uncertainty on a broad scale. The policy maker is thus left with a difficult choice.

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