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# Risk and environmental allocation

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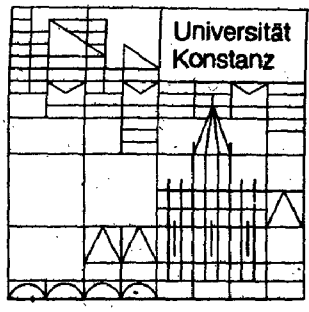
Diskussionsbeiträge

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# Risk and Environmental Allocation

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# RISK AND ENVIRONMENTAL ALLOCATION

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# Risk and Environmental Allocation *

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Uncertainty is an important aspect of the environmental issue quite a few of the basic functions describing the role of the environment for the economic system are not well known "ex ante". Emissions interact through rather complex and intricate systems and pollutants such as DDT accumulate through natural chains in a way that often is only discovered "ex post" with some delay. Variables strategic for the analysis of environmental allocation can therefore be considered as random variables. Pollutants as a by-product of our economic activities include the risk of potentially generating negative environmental impacts in the future. Risk of environmental effects may relate to small scale issues such as the eutrophication of a pond or to global problems as the heavily debated greenhouse effect from an increase in carbon dioxide or the destruction of the ozone layer. The problem arises what types of risk exist in using the environment, how these risks will influence environmental use if some optimal environmental quality is strived for, what implications will follow for environmental policy instruments and how the costs of risk reduction should be allocated to the decentral subsystems of a society.

## Environmental Risks

Risk means that the implications of a decision cannot be fully determined "ex ante". Variables or interdependencies affecting a decision are random, i.e. the occurance of a specific value of a variable depends on a state of nature which cannot be controlled by the agent. 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. Normally it is assumed that an agent can attribute probabilities to a variety of outcomes, i.e. the agent knows a density function for the random variable.

Attitudes towards risk may vary between individuals. People may be risk averse, risk neutral or risk lovers. Consequently, a given probability distribution or (assuming a normal distribution) a given variance in a specific variable may not imply the same risk for different agents. Moreover, if all agents were to have the same risk attitude, the probability distribution of a specific variable may be relevant to one agent, but not to the other. Consequently, risk can only be defined with respect to the objective function and the restraint set of a specific agent. The risk that is specific to the objective function and the restraint set of an individual agent is called private risk. This type of risk is not correlated across persons and is also labelled independent risk (Dasgupta 1982, p. 81). If, however, a public good is a ran-

dom variable we speak of social risk. Then the risk is correlated across persons, that is the risk is dependent. By definition, pure social risk must relate to all agents in the same way. Private risk can be shifted to another agent if he or she is willing to take over that risk possibly because a given probability distribution does not influence the target as negatively or even in a positive way. Social risk, however, cannot be shifted.

In the case of the environment, different types of risk relating to the different roles of environment can be distinguished. There is uncertainty with respect to the accumulation, the interaction and the spatial transport of pollutants. This type of risk relates to the diffusion function or to variables in the diffusion function. There is also uncertainty with respect to damages of a given quantity of pollutants. The magnitude of damages may not be known or the time when the damage arises may be undetermined. A specific problem may arise if threshold effects prevail and if the properties of these threshold effects cannot be determined "ex ante". Similarly, there may be the risk that a specific type of environmental use is irreversible. Other risks relate to the assimilative capacity of the environment or the generation of pollutants from consumption and production. Costs of abatement as well as production technologies may not be known "ex ante".

We are here mainly interested in the risk of environmental degradation for society as a whole where the environment is treated as a public good. Some risks in the area of environmental use may, however, be defined for specific agents. For instance, in the in-

terpretation of the new political economy, the policy maker with the objective of being reelected faces the risk that the preferences of individuals with respect to environmental quality shift and that he may not have correctly anticipated the preference changes of individuals. The individual polluter, i.e. a firm, is exposed to the risk that he will be held liable for the pollution caused or that environmental policy instruments will vary over time.

In our analysis of environmental allocation we have stressed that the role of the environment as a consumption good relates to the public goods aspect whereas the environment as a receptacle of waste is a private good. Consequently, all risks referring to the public goods aspect of the environment are social risks where risk shifting is impossible and where the appropriate approach is risk reduction. The costs of risk reduction, however, can be attributed to those who use the environment as a receptacle of wastes.

In the discussion of the environment as a public good the free rider is a central issue. This problem also arises in the case of social risk when the probability distribution or (assuming a normal distribution) the variance in a variable representing a public good has to be evaluated. In this context, risk attitudes come into play. The risk attitude of a society can be considered as the aggregation of the risk attitudes of its individual members. Thus, determining the risk attitude of a society poses similar problems as establishing the time preference rate.

In addition to the aggregation of given individual risk attitudes, the perception of uncertain phenomena plays a decisive role for the aggregation problem and for policy making. Perception of uncertain phenomena by a specific agent depends on his information and consequently on the distribution of information in society, so that the question arises whether perceptions and beliefs should be aggregated in the same way as individual preferences or whether time should be allowed for information to spread and for perceptions to change. Then, optimal allocation of risk should be based on ex-post and not on ex-ante perceptions (Dasgupta 1982, p. 70).

## Risk and Environmental Quality

From a policy point of view, uncertainty relates to the impact of pollutants on environmental quality. A simple way to introduce risk is to interprete assimilative capacity in each period $\tilde{S}^a$ as a random variable being identically and independently distributed over time. Alternatively, risk may be introduced into the damage function

$$U = G\ (S,\ \tilde{\theta}) \qquad (1)$$

so that environmental quality U becomes a random variable depending on the stock of pollutants and on states of nature $\tilde{\theta}$. Equation 1 can be simplified by assuming either that risk is additive

$$U = G\ (S) + \tilde{\theta} \qquad (1a)$$

or that risk is multiplicative

$$U = \tilde{\theta}\, G\,(S) \qquad \text{with} \qquad \theta \leq 1 \tag{1b}$$

and $G_s$, $G_{ss} < 0$. Introducing randomness into a variable of the constraints in a maximization problem implies that the target variable itself becomes a random variable so that the policy maker maximizes the expected utility of the target variable subject to the constraints. Note that in equation 1b risk is assumed to be distributed identically and independently over time.

Assume that social welfare W depends on a private good Q and on environmental quality U. For simplifying purposes only one private good is considered. The welfare function is assumed to be well-behaved.

$$W = W\,(Q,\ U) \tag{2}$$

In order to model risk attitudes in the interpretation of the expected utility theory, let $\Gamma$ denote a utility function indicating risk attitudes of society. Then the expected utility of social welfare in any given period is $E\Gamma\,[W\,(Q,\ U)]$. The policy maker maximizes the present value of expected utility from the welfare of society

$$\int_0^{\infty} e^{-\delta t}\ \{\ E\ \Gamma\ [W\ (Q,\ U)]\}\ dt \tag{3}$$

subject to equation 1b and the usual constraints. The maximization problem is spelled out in Appendix A.

The country is risk averse if $\Gamma' > 0$, $\Gamma'' < 0$. According to the expected utility theory the risk averse country chooses a linear combination of the possible outcomes. Thus, the country chooses the expected utility of welfare at point B instead of point A in Figure 1a if the spread is $\alpha$ around the mean $\bar{U}$ and if the states $\bar{U} - \alpha$ and $\bar{U} + \alpha$ both have the probability 0.5. Consider now a mean-preserving spread in the random variable $\tilde{U}$, i.e. a stretching of the probability distribution around a constant mean. Then the country will choose point B' instead of B. Thus, an increase in the spread will reduce $E\Gamma [W(U)]$ for a given U.

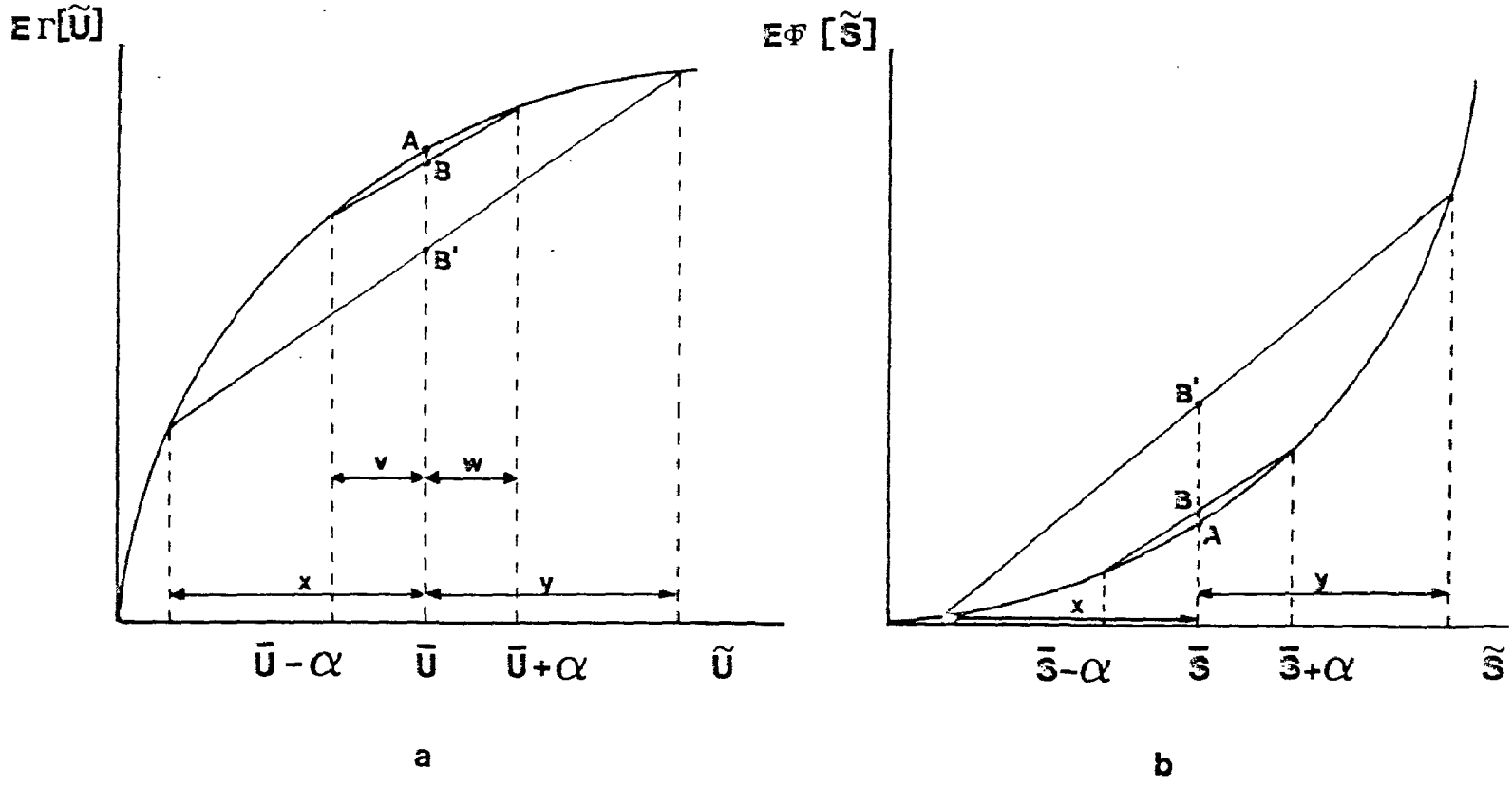


Figure 1. Expected Utility and Disutility

Due to equation 1b expected disutility can be expressed as a function of the stock of pollutants S. Expected disutility of a stock of pollutants increases progessively with S due to Gs, Gss < 0. A risk-averse agent will again choose a linear combination of possible outcomes such as point B in figure 1b. A mean-preserving spread in assimilative capacity or in $\tilde{\theta}$ will increase the expected disutility of pollutants (point B' instead of point B in figure 1b).

Whereas a mean-preserving spread definitely decreases expected utility of welfare from environmental quality (and increases expected disutility of welfare from pollution), the impact on expected marginal utility and disutility is indeterminate. From equations 3b and 1b expected marginal disutility of pollutants is defined by

$$-E\Gamma' \left[W\left(Q, G\left(S\right)\right)\right] \; W_U' \; \tilde{\theta} G_S' \left(S\right) = -E\Gamma' \left\{S\right\} \geq 0 \qquad (4)$$

The shorter term on the right hand side will be used in the text. Note that the curve $\Gamma(\cdot)$ and consequently $\Gamma'$ is not affected by a mean-preserving spread but that $E\Gamma(\cdot)$ and $E\Gamma'(\cdot)$ will be influenced. The points of the curve $E\Gamma(\cdot)$ can be constructed geometrically for a given spread similar to point B in figure 1a. A mean-preserving spread will shift the $E\Gamma(\cdot)$ curve downward. However, even if we assume risk aversion, i.e. $\Gamma'' < 0$, the impact of a mean-preserving spread on marginal disutility will also depend on how risk aversion ($\Gamma'$) changes with income or in our model with output Q. Neglecting the income effect and assum-

ing that the planner is especially risk averse, a mean-preserving spread implies a higher expected marginal utility of welfare from environmental quality and thus a higher expected marginal disutility of welfare from pollution.[1] This is assumed to hold if risk is introduced as an increase in the spread of $\tilde{\theta}$; it is also assumed to hold if the spread in the random variable $\tilde{S}^a$ is increased with $\theta$ being set equal to one.

## The Steady State

Conditions specifying the optimal use of the scarce input in production and abatement confirm the results of the case under certainty. The shadow price of the resource is equal to its marginal value product in production and abatement (Equations A.3c and d in the appendix). The contribution of a unit of output and a unit of environmental quality to welfare of society are now corrected for the marginal utility indicating a risk attitude (Equations A.3a and b).

Considering only the case of risk as the variance in $\tilde{\theta}$, we determine the properties of the steady state and the paths leading from a given situation to the steady state. The steady state is characterized by a situation which can be sustained indefinitely, i.e. in which the stock variables and the auxiliary variables do not change. For the shadow price, $-\mu > 0$, we have from equations A.3g, b and 4

$$-\dot{\mu} = -\delta\mu + E\Gamma'(S) \qquad (5)$$

The $-\dot{\mu} = 0$ Curve.

Setting $-\dot{\mu} = 0$ we have

$$-\mu\Big|_{\dot{\mu}=o} = \frac{1}{\delta} E\Gamma'(S) \qquad (5a)$$

The $-\dot{\mu} = o$ curve increases progressively[2] with S. If $-\mu$ lies above the curve, $-\mu$ rises; if it lies below the curve, $-\mu$ falls.

The $\dot{S} = 0$ Curve

The resource use in production and in abatement activity depends on the level of the shadow price $-\mu$. With an increasing $-\mu$, more resources are used in abatement and fewer are used in production.

$$\dot{S} = H\{F[R(-\mu)]\} - F^r[R^r(-\mu)] - S^a \qquad (6)$$

A high $-\mu$ reduces the production of pollutants and increases the quantity of abated pollutants. A low $-\mu$ implies a greater production of pollutants and a smaller abatement. There is a shadow price $-\mu^*$, for which $\dot{S} = 0$, or

$$\dot{S} \gtrless 0 \iff H\{F[R(-\mu)]\} - \tilde{S}^a \gtrless F^r[R^r(-\mu)] \iff -\mu \lesseqgtr -\mu^* \qquad (7)$$

Thus, the curve $\dot{S} = 0$ is a horizontal line with an axial section $-\mu^*$. Above the straight line $-\mu^*$, $\dot{S} < 0$ holds true, that is, S

falls. Beneath the straight line $-\mu^*$, $\dot{S} > 0$ is valid, that is, S increases.

Consider a given risk $\tilde{\theta}$ in the damage function and neglect the variance in the assimilative capacity. Then the steady state P with $S^*$ and $-\mu^*$ can be described in figure 2. Starting from a situation of high initial pollution S(0), a stable situation $S^*$ can be reached by the saddle path 1. A high initial penalty on pollution is an incentive to abate and reduce the stock of pollutants. Over time, the penalty is reduced.

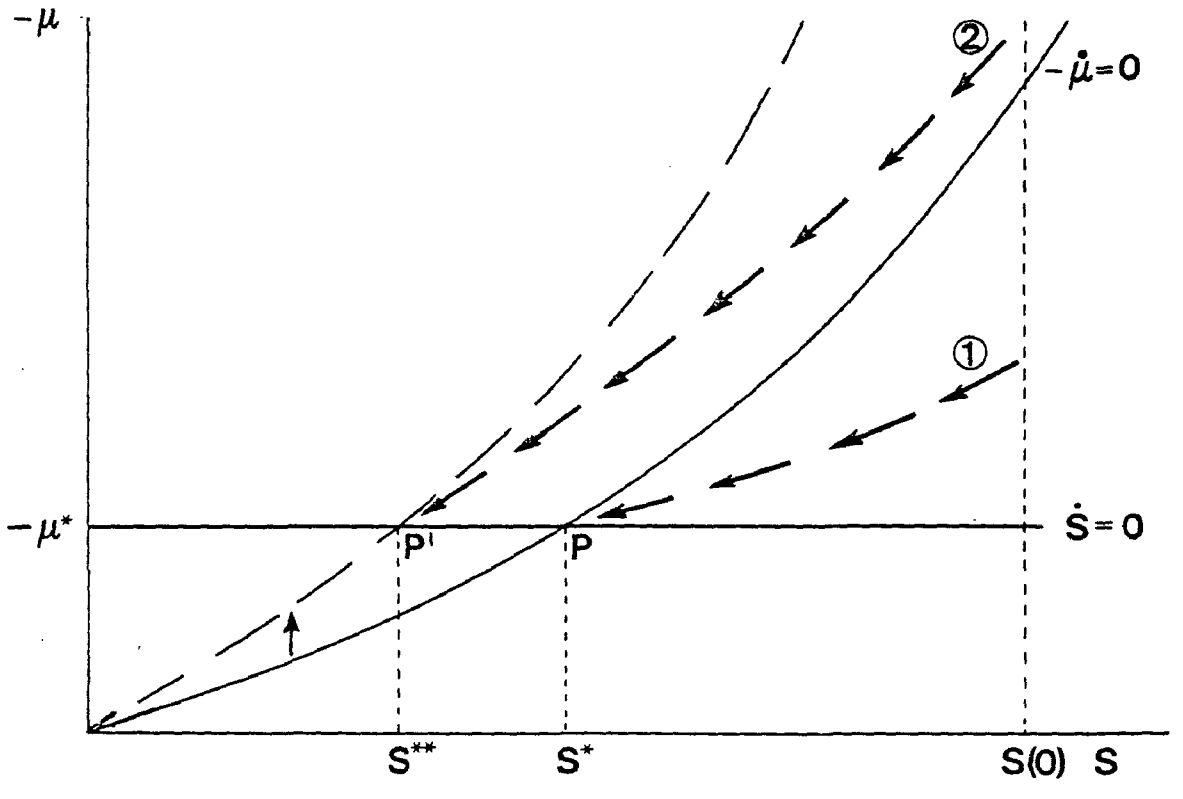


Figure 2. Risk in the Damage Function and Steady State

## Increased Risk in the Damage Function

Assume now that the risk in the damage function in each period is increased, for instance by a mean-preserving spread with more weight in the tails of the distribution. How will the steady state and the optimal path from a given initial level of pollution be affected? We consider the case that the marginal expected disutility of a given level of pollution as defined in equation 4 will be increased (see above). Then, the $-\dot{\mu} = 0$ curve will shift upward; this implies that the steady state P moves to the left point P' in figure 2.

With more risk in the damage function, the time profile of the shadow price has to change if the initial level of pollution S(0) is to be transformed into the new steady state S**. The penalty for pollution will be higher initially as well as on the way to the steady state. In any given period before the steady state, the shadow price (in absolute terms) will be higher forcing the economy to generate less pollution. Thus, an increased uncertainty in the damage function implies a lower level of pollution.

The result depends on the assumption that increased uncertainty of environmental damages will increase the expected marginal disutility of pollution (for a given level of pollution) and that thus the $\dot{\mu} = 0$ curve is shifted upward. It can be shown that this assumption implies that the planner has no incentive to reduce the

increased risk of environmental quality by just having a lower environmental quality.[3)]

An increase in risk aversion of the policy maker will shift the curve of expected disutility in figure 2 upward, and thus will shift the $\dot{\mu} = 0$ curve upward. Consequently, if the uncertainty in the damage function remains unchanged and if risk aversion is increased, the steady state shifts to the left implying a Pontryagin path with a higher penalty on emissions.

In the analysis so far it has been assumed that risk is distributed identically and independently over time. If variance in the damage function increases over time, a lower level of pollution will be allowed in the steady state implying a higher shadow price for pollutants. Ecologists hold that threshold effects are typical for environmental damages so that information on environmental changes may only become apparent after pollutants had had their impact for a longer time. This would imply that risk is not distributed identically and independently over time.

## Increased Risk in Assimilative Capacity

Assume now that the risk of the assimilative capacity in each period is increased, again by a mean-preserving spread with more weight in the tails of the distribution, whereas $\theta$ is set equal to one. How will the steady state and the optimal path from a given initial level of pollution be affected? In contrast to the

discussion on $\tilde{\theta}$-risk, our analysis now follows more intuitive and speculative reasoning.[4] Consequently, our results are conjectural and should be interpreted with some caution.

We assume that the marginal expected disutility of a given level of pollution as defined in equation 4 will be increased if there is more risk in assimilative capacity. Then, the $-\dot{\mu} = 0$ curve will shift upward; this implies that the steady state P moves to the left (point P') in figure 1b. Moreover, for $\dot{S} = 0$ to hold in equation 7, fewer emissions are required for a greater uncertainty in the assimilative capacity. This is only possible, if the shadow price $-\mu$ rises. The $\dot{S} = 0$ curve shifts upward. The steady state shifts from P to P'''.

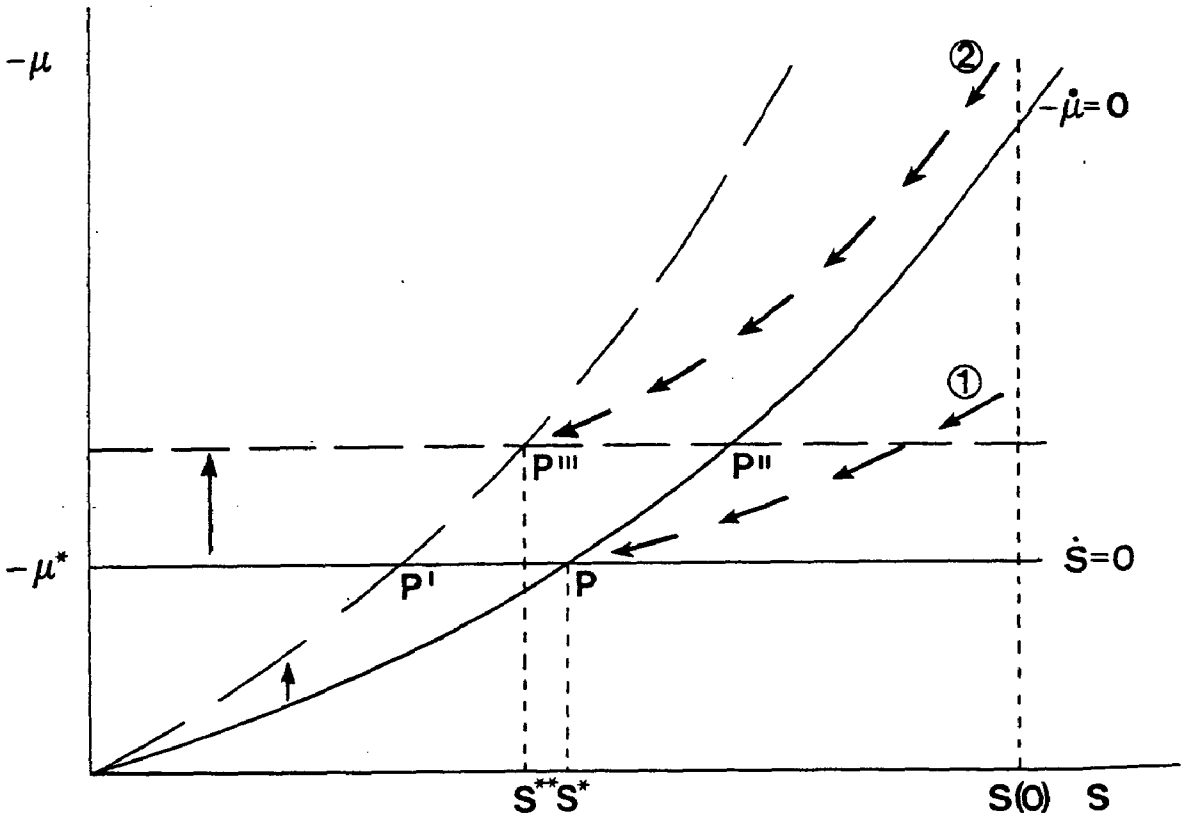


Figure 3. Risk and Steady State

The impact of an increase in the uncertainty of assimilation on the steady state can thus be broken down into two effects: First, an increased uncertainty in the assimilative capacity of the environment implies an increase of disutility of welfare from pollution. The $-\dot{\mu} = 0$ curve shifts upward (movement from P to P'). Second, assimilation becomes less likely, so that the $\dot{S} = 0$ curve shifts upward as if assimilative capacity would be reduced parametrically. (Movement from P to P'') Lower assimilative capacity implies a larger stock of long-run pollution. This is due to the fact that abatement involves costs in terms of resource use foregone in production. The increase in the tolerable level of pollution, however, is restricted by welfare progressively declining with pollution.

With the increase in assimilative risk, the time profile of the shadow price has to change if the initial level of pollution S(0) is to be transformed into the new steady state S**. The penalty for pollution will be higher initially as well as in the steady state. In any given period, the shadow price (in absolute terms) will be higher forcing the economy to generate less pollution. Thus, an increased uncertainty in the assimilative capacity of the environment implies a lower level of pollution.

In figure 3 it has been assumed that the shift in the $\dot{\mu} = 0$ curve (PP') is stronger than the shift in the $\dot{S} = 0$ curve (PP''). We cannot exclude the opposite case with the movement PP'' domi-

nating. In this case, it is conceivable that $S^{**} > S(0)$, so that $-\mu$ will actually rise over time and the system will move into a higher long-run level of pollution. This is due to the increased costs of abatement. Note, however, that $-\mu$ will be on a higher time path due to increased environmental scarcity.

## Preventive Environmental Policy

Figure 2 illustrates the concept of preventive environmental policy (O'Riordan 1985, Simonis 1984). With the environmental impact of pollution being uncertain, a higher environmental quality is optimal in the steady state. In order to reach less pollution in the long run, a higher penalty has to be put on pollution. Thus, environmental risks make the environment more scarce. Higher environmental quality can be interpreted as an insurance against the risk of environmental degradation or as a risk premium.

Note that preventive environmental policy varies with the risk aversion of the policy maker. If he is very risk-averse, he will ask for a low level of pollution as an insurance against the risk of environmental degradation. The costs of environmental protection will be relatively high, and they will vary with risk aversion.

Preventive environmental policy also depends on the discount rate. Future disutilities are discounted thus having a lower weight in the present value of expected welfare. Therefore, the present

value of welfare can be increased if the disutilities are postponed into the future, that is if a unit of pollution is accumulated at a later date. As in the case of certainty, a higher discount rate implies a lower environmental quality.

## Irreversibilities

An important aspect of environmental risks are irreversibilities. When uncertain negative effects on the environment can be remidied in the future, risks may not be such a pressing problem. We only shift the costs of restoring or improving the environment to future generations. This still holds when the costs of restoration are very high. In the case of a pure irreversibility, however, the costs to remedy a negative environmental impact are infinite. Apparently, there exists a continuum of restoration costs between zero and infinity.

Environmental risks represent a serious problem if restoration costs are infinite, that is if pure irreversibilities exist. Examples are the extinction of a species or the destruction of a landscape that cannot be restored. Krutilla and Fisher (1975) have exemplified the problem with the Hells Canyon case where a Canyon is given up for a mine. Henry (1974) has discussed the problem of irreversibility with the example of turning Notre Dame in Paris into a parking lot.

Pure irreversibilities give rise to the question whether future benefits should be discounted. One solution to the problem is to

use a lower discount rate, thereby giving more weight to the opportunity costs of the future. As an extreme case, if an irreversibility is judged to be crucial, a zero discount rate has to be applied. An alternative solution of handling irreversibilities is to explicitly introduce an option value being defined as the value, in addition to expected consumer's surplus from actually using a good, that arises from retaining an option to a good or service for which demand is uncertain (Krutilla and Fisher 1975, p. 70). For a risk-averse agent, the option price, i.e. the willingness-to-pay for keeping up an option, exceeds the expected consumer's surplus. Thus, the option value can be interpreted as an insurance premium or a risk premium against the irreversible loss of an alternative. Since the environment is a public good, the willingness to pay for an option cannot be determined by the market but must be established by other processes such as voting.

The concept of option value allows to introduce a specific value for avoiding an irreversibility. Note, however, that the debate on the discount rate or on the weight to be given to future generations cannot be completely separated from the determination of the option value. The option value will be affected by the discount rate.

If with the passage of time new information becomes available on the benefits and costs of a specific environmental use (Arrow and Fisher 1974), the relevance of irreversibilities will only come to light over time. Consequently, there is a positive option value even if the policy maker is not risk-averse.

## Allocating Environmental Risks?

What institutional setting should be chosen in a society for the allocation of environmental risks and for the allocation of the costs for risk reduction? As an extreme answer to these two problems we perform a Gedankenexperiment and assume that exclusive property rights for the environment can be clearly defined so that the free rider does no longer exist. By this assumption, the environment has become a private good and environmental risks are no longer social risks. Assume bargaining costs and other transaction costs are zero. Assume also that the agents have objective probabilities for the occurence of specific states of nature. Then a Coase theorem (1960) should hold for a world with environmental risk where risk allocation will be optimal in the interpretation of Coase. Externalities relating to risk are perfectly internalized and the Coase theorem can be interpreted as the analogon to the Modigliani-Miller theorem (1958) for a world of environmental allocation. Stochastic phenomena would be transformed into deterministic market values.

We know that in the case of environmental risks such a situation cannot hold. Property rights cannot be clearly defined because the environment is a public good and not all facets of the public good can be taken away by specifying exclusive property rights. Transaction costs prevail. As a matter of fact, in an institutional setting with private property rights, transaction costs can be expected to be rather high. One aspect of transaction costs in the case of uncertainty would be liability arrangements

with reliance on the judicial system. The increased role of courts would imply an ex-post allocation of risk and would give rise to a large uncertainty in private decisions. Thus, it is rather unrealistic to assume that environmental risks can be efficiently allocated through a Coase type scenario.

The risk of environmental degradation cannot be shifted because by definition the environment is a public good and the risk of its degradation is a social risk. The appropriate policy therefore is risk reduction.

## Risk Reduction

The formal model presented in the previous sections takes a rather general and broad approach to risk reduction, namely to establish a higher environmental quality which can be interpreted as an insurance or a risk premium against uncertain environmental degradations. This approach of risk management may prove to be rather coarse and rough in the sense that a more detailed analysis of the risks envolved may allow to reduce the risk in a more sophisticated way. Consider for instance the case where environmental quality is measured by an index of several pollutants in different environmental media. Then preventive environmental policy requires that all pollutants are reduced in the proportion of their weight in the index. Apparently, risk management could be improved considerably if information would be available in the specific impact of different pollutants in different media. Research on the en-

vironmental impact of pollutants may increase information and thus reduce uncertainty.

A more detailed analysis of environmental risks would attempt to model these risks more specifically. An important aspect are the worst case scenarios which have a rather low probability of occuring, but would have tremendous negative impacts. An approach here is to cut off these cases. Of course, such an approach would depend on the costs involved. As an alternative approach, offsetting options may be kept open, and research on offsetting options for the worst case may represent an insurance premium (Dasgupta 1982, p. 74). Other aspects of a more precise modelling of environmental risks are the consideration of irreversibilities (see above) and restoration costs where applicable as well as the postponement of damages into the future (excluding irreversibilities) in the sense of diversification over time. Also a regionalization of public bads may be considered. For instance a hot spot policy, though in conflict with equity considerations, implies some type of spatial risk spreading.

## Allocating the Costs of Risk Reduction

An important aspect of environmental risk management is how the costs of risk reduction are allocated to the agents causing the risks. In contrast to natural hazards such as earthquakes an important ingredient of environmental risks is man made, namely pollutants. Thus, one strategy of risk reduction is to attribute

the costs of reducing the social risks to the decentralized units of the economy. By efficiently allocating the costs of risk reduction to those decentralized units that cause the social risk in the first place, an incentive is introduced to reduce the social risk. If the environment can be used free of charge as a receptacle of waste, no incen- tive is introduced to reduce emissions. If emission taxes, other pricing instruments for emissions and other policy instruments are applied, in a rather general way some of the social risk of environmental degradation is reduced. Thus, in a world with risk, we have to make use of the polluter-pays-principle; it requires that the costs of risk reduction should be attributed to the polluter.

The issue is to find not only an institutional mechanism that allows to attribute the costs of reducing environmental risks but also a mechanism that can be flexibly adjusted to new environmental situations coming to the foreground if damages are reversible. Which instruments should the regulator choose that allow a quick response to environmental degradation (Dasgupta 1982, p. 81)? When the attribution of social risks cannot follow flexibly to the arising of new damages or risk, i.e. when environmental policy cannot react quickly with its policy instruments to unforeseen damages, either the damages will be borne by the public as a public bad or the costs of damage reduction will be left with the government. Then the costs of risk reduction are not attributed to the polluter, and social risk will not be reduced in an efficient way.[5] Of course, if irreversibilities prevail, the flexibility of the policy response is not an issue.

The problem whether the political process can react swiftly to new environmental situations relates to two different aspects. First, the total quantity of tolerable pollutants ambient in the environment may have to be reduced quickly; second, instruments specifying emissions may have to be changed. The problem arises whether some policy instruments are better in taking into account the problem of uncertainty. Some people favor standards for individual facilities in order to cope with this type of uncertainty of environmental degradation claiming that the individual polluter can be controlled much better. However, it is highly questionable that in an institutional setting with emission norms for individual agents, that is non-transferable permits, the total level of pollutants ambient in the environment can be changed more easily than in a setting of emission taxes or transferable discharge permits. Emission standards and non-transferable permits may prove to be rather rigid in reality. Price mechanisms allow a better allocation of the scarce volume of tolerable emissions if emission taxes or effluent fees can be changed in some quasi-automatic way without parliamentary action for each change. Also, transferable permits will signal quickly variations in environmental scarcity. Moreover, price instruments will introduce a more stimulating incentive to reduce emissions in the long run.

## The Response of the Polluter under Uncertainty

The problem of risk reduction is more complicated than just to introduce incentives to lower emissions. The problem is that the environmental impact of pollution is uncertain. And the question

is how this uncertainty should be reflected in the institutional mechanism of attributing the costs of risk reduction. The problem is aggravated by the fact that the agent drawing up the institutional setting does not only lack information on the impact of the level of pollution on the environment, but he or she also does not know how the individual firm or the individual household will react to the policy instruments chosen. The policy maker is unaware of the firm's abatement and costs function, its technology etc. When devising an institutional mechanism the regulator does not know the reactions of the different agents and, given their reaction, he does not know how their response will influence his policy target. In the German economics literature this general problem of economic policy has been studied under the heading Ordnungspolitik (Eucken 1952); more recently it has become known as the principal-agent problem.

How the individual polluter will steer this abatement processes if he faces uncertainty on the environmental policy instruments to be used (Dasgupta 1982, Dasgupta, Hammond and Maskin; Kwerel 1977) becomes relevant because the individual polluter experiences costs of adjustment when environmental policy is changed. These costs relate to capital costs, because abatement capital cannot be adjusted to new policy instruments quickly. Costs also relate to the production technology and such phenomena as location as well as sectorial and regional structure. In the case of uncertainty, the individual polluter will form expectations on the policy instruments used, and these expectations will influence his abatement behavior. Moreover, the polluter as a po-

litical group will attempt to reduce uncertainty by influencing policy instruments. Environmental policy instruments should be devised to reduce adjustment costs and to prevent "overshooting".

**Notes**

* Forthcoming in Siebert (1987).

[1] This procedure represents an ad hoc short-cut. Following Sandmo (1971, p. 67), we write the random variable $\tilde{\theta}$ as $\gamma\breve{\theta} + \xi$ where $\gamma$ and $\xi$ are multiplicative and additive shift parameters, respectively.

Assume

$$dE\,[\gamma\tilde{\theta} + \xi\,] = 0 \qquad \text{or} \qquad E\,[\tilde{\theta}]\,d\gamma + d\xi = 0, \text{ i.e.}$$

$$\frac{d\xi}{d\gamma} = -\,E\,[\tilde{\theta}]$$

Then the optimality conditions in each period and for the steady state should be shocked by a change in $\gamma$. This exercise then would clearly indicate how the optimal solution, i.e. the optimal values for S*, U* and the other variables, is affected by a mean-preserving spread. Instead, we let $\tilde{\theta}$ be influenced by a parameter $\gamma$, allowing a change in the mean. Moreover, we consider a given level of pollution and thus we neglect the change in the level of pollution induced from an increased risk. Then, according to equation 4, the expected marginal disutility of pollutants is given by

$$-E\Gamma'(S,\gamma) = -E\{\Gamma'[W(Q,\tilde{\theta}(\gamma)\cdot G(S))]\cdot W_U\,[Q,\tilde{\theta}(\gamma)\cdot G(S)]\cdot\tilde{\theta}(\gamma)\cdot G'(S)\} \qquad (1)$$

We neglect the impact of stretching the probability distribution on Q, that is we neglect the impact of a change in income on risk aversion. Then, derivation with respect to $\gamma$ yields

$$\partial[-E\Gamma'(S,\gamma)]/\partial\gamma = -E\{\Gamma''\cdot W_U^2\cdot G(S)\cdot\tilde{\theta}(\gamma)\cdot G'(S)\cdot\tilde{\theta}'(\gamma)\}$$

$$-E\{\Gamma'\cdot W_{UU}\cdot G(S)\cdot\tilde{\theta}(\gamma)\cdot G'(S)\cdot\tilde{\theta}'(\gamma)\}$$

$$-E\{\Gamma'\cdot W_U\cdot G'(S)\cdot\tilde{\theta}'(\gamma)\}. \qquad (2)$$

Rearranging terms we have

$$\frac{\partial[\quad]}{\partial\gamma} = -E\{\Gamma''\cdot W^2{}_U\cdot G(S)\cdot\tilde{\theta}(\gamma)\cdot G'(S)\cdot\tilde{\theta}'(\gamma)\}$$

$$-E\{\Gamma'\cdot G'(S)\cdot W_U\cdot[1+U\cdot W_{UU}/W_U]\cdot\tilde{\theta}'(\gamma)\} \qquad (3)$$

Let a parametric increase in $\gamma$ make a lower $\theta$ more likely and reduce environmental quality, that is $\tilde{\theta}'(\gamma) < 0$, as shown by the shift in the density function in figure 4a. Then

$$-U\cdot\frac{W_{UU}}{W_U} > 1 \qquad (4)$$

is a sufficient condition for the expected marginal disutility of pollutants to rise with a parametric increase in $\gamma$ (neglecting the impact of a change in income on risk aversion). Note that this condition is not necessary.

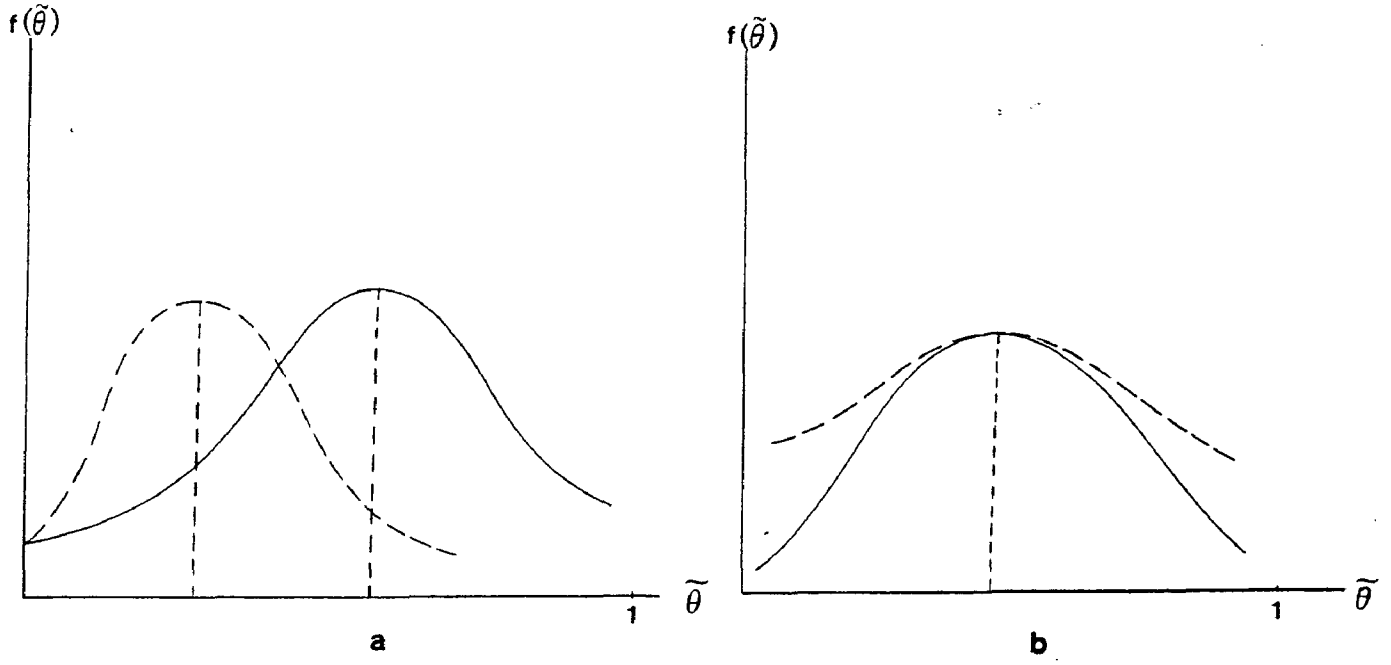


Figure 4. Increase in Risk and Probability Distribution

Condition (4) requires a "strong" curvature of the welfare function with respect to environmental quality. Curvature in the welfare function can be a means to express risk aversion. Thus, the marginal expected disutility of pollutants will rise if the policy maker is sufficiently risk averse.

Note that introducing risk aversion into the usual utility function should not be confounded with the use of the expected utility function $\Gamma$.

The third term in equation 2 is negative; this term captures the impact of a parametric change in $\gamma$ on expected marginal disutility for a given level of pollution assuming a given marginal damage and a given marginal utility. Set $\tilde{S} = \tilde{\theta}S$, then the third term of equation 2 can be written as

$$- E \left\{ \frac{d\Gamma}{dW} \cdot \frac{dW}{dU} \cdot \frac{dU}{d\tilde{S}} \cdot \frac{d\tilde{S}}{d\tilde{\theta}} \cdot \frac{d\tilde{\theta}}{d\gamma} \right\} \Big|_{\bar{S}} < 0$$

According to this effect, captured in the third term of equation 2, expected marginal disutility of pollution will be reduced, that is, marginal utility will increase due to more randomness in environmental damages. If only this effect (of the third term of equation 2) would prevail, the planner would increase pollution in order to reduce the randomness in environmental quality. If environmental quality is sufficiently low (and if the damage function 1b prevails which excludes for instance threshold effects) a larger spread does not imply a big loss in welfare. Thus, the planner can reduce risk by having a lower environmental quality (according to the third term). However, if the planner is sufficiently risk averse, for instance, if condition 4

prevails, he will not follow that policy. I owe the derivation and some stimulating questions on this point to Ernst Mohr.

If we assume a mean-preserving spread as in figure 4b, total derivation of equation 1 yields

$$d[-E\Gamma'(S,\gamma)] = -E\{\Gamma''' \cdot W^2{}_U \cdot G(S) \cdot G'(S) \cdot [\tilde{\theta} d\gamma + d\xi] \cdot [\gamma\tilde{\theta} + \xi]$$

$$-E\{\Gamma' \cdot W_{UU} \cdot G(S) \cdot G'(S) \cdot [\tilde{\theta} d\gamma + d\xi] \cdot [\gamma\tilde{\theta} + \xi]$$

$$-E\{\Gamma' \cdot W_U \cdot G'(S)(\tilde{\theta} d\gamma + d\xi)\} \qquad (5)$$

Again, an increase in risk makes a lower value of $\theta$ more likely, to that $\tilde{\theta} d\gamma + d\xi < 0$. Equation 5 can be interpreted in the same way as equation 2.

[2] For a given $\theta$, the change in $-\mu$ is given by

$$\frac{d(-\mu)}{dS} = -\frac{1}{\delta}\{E\Gamma''(\cdot) W_U'^2 \theta^2 G_S'^2 + E\Gamma'(\cdot) W_U'' \theta^2 G_S'^2$$

$$+ E\Gamma'(\cdot) W_U' \theta G_S''\} > 0$$

due to $\Gamma''$, $W''_U$, $G'' < 0$. The second derivation will be negative if $G''' < 0$, $W''' > 0$ and $\Gamma''' > 0$.

[3] Compare footnote 1.

[4] For a more formal analysis, a similar derivation as in footnote 1 would be necessary with respect to $\tilde{S}^a$.

[5] Note that there is a trade-off between flexibility and the insurance premium. If environmental policy cannot react quickly to unforeseen environmental damages, a higher insurance premium is mandated, i.e. a higher environmental quality has to be established.

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Appendix A.
An Intertemporal
Allocation with Risk

The allocation problem for environmental use under uncertainty consists in maximizing the welfare function

$$\omega = \int_0^\infty e^{-\delta t} \{ E\Gamma[W(Q,U)] \}\, dt \qquad (A.1)$$

under the following restrictions:

$$\dot{S} = S^p - S^r - \overline{S^a} \qquad (A.2.)$$

Furthermore the restrictions of the static allocation approach of equations 3.1 through 3.6 (Siebert 1987) apply for every period. For simplifying purposes it is assumed that only one output is produced. If the problem is formulated in periodical values, the maximization problem is

$$\begin{aligned} L = {} & E\Gamma[W(Q,U)] + \mu\left( S^p - S^r - \overline{S^a} \right) - \lambda_{S^p}[H(Q) - S^p] \\ & - \lambda_Q [Q - F(R)] \\ & - \lambda_{S^r}[S^r - F^r(R^r)] \\ & - \lambda_U[U - \theta G(S)] \\ & - \lambda_R\left( R + R^r - \bar{R} \right) \quad \max \end{aligned} \qquad (A.3)$$

Necessary conditions for an optimum are

$$\frac{\partial L}{\partial Q} = E\Gamma'(.)\, W'_Q - \lambda_{S^p} H' - \lambda_Q \leq 0 \quad Q \geq 0 \quad Q \frac{\partial L}{\partial Q} = 0 \qquad (A.3a)$$

$$\frac{\partial L}{\partial U} = E\Gamma'(.)\, W'_U - \lambda_U \leq 0 \quad U \geq 0 \quad U \frac{\partial L}{\partial U} = 0 \qquad (A.3b)$$

$$\frac{\partial L}{\partial R} = \lambda_Q F' - \lambda_R \leq 0 \quad R \geq 0 \quad R \frac{\partial L}{\partial R} = 0 \qquad (A.3c)$$

$$\frac{\partial L}{\partial R^r} = \lambda_{S^r} F^{r\prime} - \lambda_R \leq 0 \quad R^r \geq 0 \quad R^r \frac{\partial L}{\partial R^r} = 0 \qquad (A.3d)$$

$$\frac{\partial L}{\partial S^p} = \lambda_{S^p} + \mu \leq 0 \quad S^p \geq 0 \quad S^p \frac{\partial L}{\partial S^p} = 0 \qquad (A.3e)$$

$$\frac{\partial L}{\partial S^r} = -\lambda_{S^r} - \mu \leq 0 \quad S^r \geq 0 \quad S^r \frac{\partial L}{\partial S^r} = 0 \qquad (A.3f)$$

$$\dot{\mu} = \delta\mu - \lambda_U \theta G' \qquad (A.3g)$$