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Abstract

This working paper examines some of the decision criteria suggested by theories on decision making under uncertainty. This is done by applying the criteria to the problem of global warming. It is shown that even if there was a benevolent planner who is both supranational and supragenerational, and even if he had a well-defined intergenerational welfare function, there are still remaining problems. The question asked is: *If* there were a benevolent planner, would he know the best climate policy for the world today?

The main discussion abstracts from all other complications and focus on the lack of certainty regarding impacts of greenhouse gas emissions and the effectiveness of policy. A very simplified example of a game against nature is constructed. It has two possible policy choices: One can either try to prevent global warming, or one can choose to do nothing. The future state of the world is uncertain, and the chosen policy might affect the outcome in each state. The framing of the example is such that one should expect a policy of action to be preferred, rather than a no-action policy, however this is not always the case. It is shown that the preferred policy choice is very much dependent on the choice of decision criterion, the magnitude of costs and of the framing.

Contents

1 Introduction

It is a world of change in which we live, and a world of uncertainty (Knight, 1971). The essence of the climate problem is thus action according to opinion, of greater or less foundation and value, neither entire ignorance nor complete and perfect information, but partial knowledge.

This essay examines, in the light of the climate problem, some of the decision criteria suggested by theories on decision making under uncertainty. It shows that even if there was a benevolent planner who is both supranational and supragenerational, and even if we had a well-defined intergenerational welfare function, there are still problems remaining. The question is: *If* there were a benevolent planner, would he know the best climate policy for the world today? The main discussion abstracts from all other complications and focus on the lack of certainty regarding impacts of greenhouse gas emissions and the effectiveness of policy. It shows that the preferred policy choice is very much dependent on the choice of decision criterion. Furthermore it is dependent on the magnitude of costs and of the framing; how states of nature is defined, and of the subjective beliefs about the probability distribution of states.

The global warming debate has shown that there are two major risks of concern. The first is the risk of significant human and ecosystem impacts from large-scale climate change in the next century, a potential environmental problem of immense dimensions. The second is the risk of incurring large economic costs now, for policies that might slow global warming or mitigate its impacts, when there is considerable uncertainty about the effectiveness of the policies as well as the severity of the problem. The debate has been over scientific evidence, but the fundamental issue of separating the two sides is rather which risk is perceived to be the greater threat (Colgazier 1991).

The supporters of the first risk being the greater argue that because of the uncertainty one should abate greenhouse gases now, in order to reduce the possibility of extensive damage. By reference to the precautionary principle, they look upon abatement as an insurance against catastrophic events. Their point is that uncertainty alone gives rise to a willingness to pay for insurance. One could easily draw a parallel to fire insurance, which is considered wise, even if one is not realistically expecting ones house to burn down.

The supporters of the second risk, however, argue that we should not impose strong policies before the state of knowledge has improved significantly. By postponing action, they argue, we may learn more about the effects and find new and cleaner technologies. Meanwhile, we can invest in alternative projects, which will make us more prepared to both abatement of greenhouse gases and to adapt to changes in the future (Kolstad 1994).

Both sides place the burden of proof on the other, and which group is right seems to be a matter of beliefs. If we believe that the probabilities of severe damage or catastrophic events are small, then a wait-and-see strategy is preferable. If, however, we believe the probability is non-negligible, immediate action must be the best strategy. This gives rise to another important question: How small must the probabilities of severe damage or catastrophic events be, in order to be considered negligible? This is much more difficult to answer. As climate change is a long-term global problem, it rises moral and intergenerational issues, and questions regarding less developed countries.

Theories on decision making under uncertainty have suggested various decision criteria. I will in the following examine some of these principles in the light of the climate problem. When discussing a decision criterion there are several possible approaches: one is to look at the axiomatic foundation; another is to focus on the practical implications; and, a third is to do both.

If accepting the axiomatic foundation underlying the criterion, then you must also accept their implications. However, axioms are abstract and often difficult to fully understand. Therefore it can be wise to look at their implications when applied to a specific problem. Philosophers[2] say we have a reflective equilibrium, when there is accordance between the intuition about the abstract implications of the axioms and the intuition of the practical implication they have, or ought to have, when applied to a problem. If this is not the case, one could adjust the axioms and compare again.

By applying the criteria to the problem of global warming, I whish to learn more about the implications of using the different decision criteria in a frame of uncertainty. The aim is to try to learn something about the criteria by moving back and forth between the abstract principles and the problem we would like to solve. As an illustration I will construct a very simplified example of a game against nature, with two possible policies: We can either try to prevent global warming, or we can choose to do nothing. The future state of the world is uncertain, and the chosen policy might affect the outcome in each state. The framing of the example is such that one should expect a policy of action to be preferred, rather than a no-action policy, however this is not always the case.

[2] See for example John Rawls (1971)

2 Risk versus uncertainty

A situation is said to involve *risk* if the attached randomness can be expressed in terms of specific numerical probabilities. These probabilities are objectively specified, as with lottery tickets, or a dice: The numbers are known. However, situations where one cannot (or does not) assign actual probabilities to the alternative possible occurrences are said to involve *uncertainty*. In this case probabilities reflect the individuals own subjective beliefs: The numbers are unknown (Knight 1971).

The question of human made global warming definitely abounds in scientific uncertainty; uncertainties in predicting the timing and magnitude of future climate change caused by greenhouse gas emissions; uncertainties in predicting the ecological, economic, social and political impacts; and uncertainties in predicting the effectiveness and costs of policy options. (Colgazier 1991) On this background, one might expect the question of how to deal with the uncertainties related to climate change to be well understood. But this is not the case. Experts disagree significantly in their recommendations of how to act[3].

Referring to the precautionary principle, some argue that we should cut emissions of greenhouse gases now. The precautionary principle has many definitions. Among the common themes are the undesirability of irreversible damage, the need to prevent and anticipate damage, and that lack of complete scientific uncertainty should not be used as an excuse for inaction (Harding & Fisher 1992). The Bergen Ministerial Declaration from 1990 states that the precautionary principle suggests that: “Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.” This suggests that there is a case for reducing carbon dioxide and other greenhouse gas emissions now, even if it is uncertain whether these emissions are contributing to the greenhouse problem, and the economic costs are uncertain, even if greenhouse damages would be inflicted (Chrisholm & Clarke 1993). This interpretation is, of course, dependent on the belief of the climate problem as “threats of serious or irreversible damage”.

The experts who question the view of the climate problem as “threats of serious or irreversible damage”, argue that one should not impose strong policies before the level of knowledge has improved. It is hardly controversial to state that we need to improve the knowledge of the impacts of climate change in order to design a better climate policy. Yet, we do not know whether improved knowledge implies less uncertainty. This is why we need more discussion of framing, what information is needed, and how to use available knowledge about the uncertainty, in order to make better decisions.

[3] This is discussed further in Bretteville & Aaheim, 1999.

3 The stylized climate problem

What is the best way to approach the climate problem? When making policy choices under scientific uncertainty in areas characterized by disagreement among experts, value judgement will have to be made about what counts as evidence. The question thus becomes; what scientific evidence is sufficient and admissible to justify a policy decision under these conditions? Where to set these standards of proof – how sure is sure enough – is a value judgement. People's values are affected both by their general principles of rights and responsibilities and by their self-interest. They might primarily be concerned about a fair decision-making process or about the fairness of outcomes. Values are significant with respect to a fair allocation of the costs, benefits and risks to initial stakeholders, and also with respect to a fair outcome for society as a whole, incorporating goals such as efficiency, stability, political feasibility, and legitimacy (Colgazier 1991).

Value judgements about risks and impacts are intertwined with evidential judgements about how sure is sure enough. The conclusions from a discussion of these issues are strongly connected to whom is asked. Both the global and the intergenerational dimension of the climate problem emphasize this (Malnes 1997). One cannot expect to solve such a complex problem with one ethical rule (Ringius 1999).

In the following section I will look past these dimensional problems and introduce a benevolent planner or principal as a theoretical abstraction. His goal is to decide what the world should agree upon, given that all problems regarding coordination and feasibility are or will be solved. In other words, I will assume that the planner has the right preferences, from an objective social point of view. He will thus take all relevant factors into consideration and decide in a morally consistent manner. This way I abstract from all other complications and focus on the lack of certainty regarding impacts of greenhouse gas emissions and the effectiveness of policy. The question is: *If* there were a benevolent planner, would he know the best climate policy for the world today? This will be discussed in light of a few decision criteria.

4 The welfare function

Consider an economy with a benevolent planner, which cares about the 'bulk' of future welfare, W, emerging from output from resources (capital) and the damage from climate change. Damage can be reduced by abatement, a. The policy goal of the planner is to maximize future welfare with given resources. The resources can be utilized for investments or abatement. Due to the uncertainty of the climate indicator, the effect of abatement on climate is uncertain. Abatement can be interpreted partly as a way to reduce the expected damage. Implicitly one can also interpret abatement as a mean to change the probability distribution for future damage.

I will in the following decision criteria discussion use a reduced form of the welfare function:

$$W = W(a, s) \tag{4.1}$$

The welfare is thus a function of abatement, a, and s, that is a parameter, or a vector of parameters, over which we have no control. s is thus representing the uncertainty in the model, and it is defined such that a high s is good, and a low s is bad. This welfare function is aggregated both over groups and over time in a suitable manner. How this should be done is a controversial matter, which will be abstracted from in the criteria discussion. Some of these controversial issues, however, are touched upon in the remaining of this section.

4.1 Dimensional problems

There are both intergenerational and transboundary problems with using but one welfare function. How would a benevolent planner weight different people, within and between generations? Are they supposed to have equal weights? The present generation is set to take care of the interests of future generations. This might be a problem. Do we care enough about the poor people of future generations in developing countries?

These questions lead to the moral aspect of the climate problem. Until recently, the developed part of the world has been the main contributor to emissions of greenhouse gases. Furthermore, the developing countries are likely to suffer the greatest losses, should climate change occur. The major sectors likely to be affected by climate change, are agriculture, together with forestry and fisheries. Agriculture plays an especially large role in the economic life of developing countries, trough food prices. Another major threat is sea level rise. Bangladesh, and a number of island economies are directly threatened by the potentially devastating effects of a rise in sea level. Thus, susceptibility of developing countries to climate change is likely to be much greater than for most developed countries. In addition, developing countries have a lower capacity than developed countries to adapt in the face of climate change (Chrisholm & Clarke 1993).

4.2 Discounting?

Another important issue is the question of discounting. One argument for discounting over time is that consumers are impatient, they have a preference of immediate over postponed consumption. A second is that the marginal utility of consumption decline with growing per capita consumption. One could question, however, the validity of the first argument, when discussing discounting in the light of the climate problem. Here we are talking about consumption fifty, hundred or several hundred years ahead. It might be difficult to justify the impatience argument, considering the time horizon. It is not the same generation consuming today and a hundred years from now. Impatience then becomes a question of moral. Some might consider it egoistic to say that our consumption today is more important, or more valuable, than the consumption of the generations to follow.

The second argument follows from an assumption about continuing future growth, which implies increased future consumption. Assuming decreasing marginal utility, this future consumption will be of less value, on the margin. This means that, given continued growth, the last unit consumed in the future has less utility value than the last unit consumed today.

It is important to note, however, that this is not about saving for the future, but rather making intergenerational transfers forward in time. We are not the ones who will consume the long-term benefits we are attempting to bring about if we reduce emissions of greenhouse gases. This is not a savings program; it is an aid program. If the economic sacrifices in the interest of climate change remedial activity is borne by the countries that can best afford it, the transfers will tend to be from people in the developed part of the world, to people in the less developed parts. Hopefully the residents of the developing countries will be far better off a century from now than they are today. However, they may not yet be as well off then, as people in the developed part of the world is today (Schelling 1993).

4.3 Time inconsistency

One of the responsibilities of present policy makers is to take care of the interests of future generations. It is a common experience, however, that people tend to postpone unpleasant tasks, preferring to have them done in the next period, even if it might be optimal to complete the task now. This might also apply to policy makers, and will probably reflect time-inconsistent preferences.

A decision rule is said to be time-consistent if at each decision node reached when the rule is followed, the decision rule is still optimal in the sense of maximizing the welfare as evaluated at the reached node. Considering the climate issue, policy makers preferences (and they might also reflect the preferences of the present generation) seem to give extra weight to current welfare over future welfare. These present-biased-preferences might lead to procrastination of climate change remedial action, a decision that might be time-inconsistent (Asheim 1997, O'Donoghue & Rabin 1999). The incentives to procrastinate stem from the fact that the policy makers plan to do a task based on its long-run benefits, and these benefits are strongly dependent on whether or not they accept taking on the costs of greenhouse gas abatement today.

5 Decision criteria

A decision problem is defined by the acts or options among which one must choose, the possible outcomes or consequences of these acts, and the contingencies or conditional probabilities that relate outcomes to acts (Tversky & Kahneman 1987). The problem raised above about whether we should abate now or wait until later, is very much a question about which decision criteria we choose.

A major theory of decision-making under uncertainty is the expected utility model. This model is based on a set of axioms, which provide criteria for the rationality of choices. In short, the preferences have the following properties: The individual's choice among actions can be represented by an ordering, and the choices are continuos. This means that, given any two actions, the individual prefers one to the other or else regards them as indifferent (the axiom of connectedness). Furthermore, if an individual is to choose between three actions a, b and c, and he prefers a to b, or is indifferent between them, and the same holds between b and c, then he must prefer a to c or be indifferent between them (the axiom of transitivity). The axiom of continuity demands that if action a is preferred to action b, then any action sufficiently close to a is also preferred to b, and action a is preferred to any action sufficiently close to b.

Additionally, the expected utility model assumes conditional preferences and probabilistic beliefs. If the individual is given information that certain states of nature are impossible, he reforms his beliefs about the remaining states of nature. On the basis of these new beliefs, he forms a new ordering of the actions. The axiom of conditional preferences then asserts that the ordering will depend only of the consequences of the actions for those states of the world not ruled out by the information. Probabilistic beliefs mean that if the probability distribution of consequences is the same for two actions, they are considered indifferent (Arrow 1965).

The choices of an individual, whose actions are consistent with the axioms, can be described in terms of the utilities of various outcomes for that individual. The utility of a risky prospect is equal to the expected utility of its outcomes, obtained by weighing the utility of each possible outcome by its probability. When faced with a choice, the model says that a rational decision-maker prefer the prospect that offers the highest expected utility.

5.1 Maximizing expected social welfare

This criterion can be formulated as follows:

$$\max_{A}\left\{E_s W\left(A,s\right)\right\} \tag{5.1}$$

Where A is the policy choice that determines the level of abatement. $W(A,s)$ denotes the social welfare as a function of the planners policy choice and uncertainty. Thus, the criterion says that one should choose the level of abatement that maximizes the expected social welfare.

Suppose the planner has to choose between climate change remedial action, or action according to the precautionary principle (PP), as it also will be denoted here, and no action

(NA). The problem is interpreted as a game against nature, a non-strategic player. This is a common way of illustrating decision problems, and the example used builds especially on Chrisholm & Clarke 1993. Suppose further that the costs of adopting the precautionary principle, denoted *C*, include both the policy costs and the social costs of output forgone. The possible damage from climate change is denoted *D*, and I assume that this damage is far greater that the cost of implementing a policy of remedial action. In the following I assume the damage from future climate change to be at least three times the cost of implementing the precautionary principle $D > 3C$.

Suppose also that there are three possible future states of the world:
S_1 = damage from climate change (D) is severe in the absence of PP
S_2 = damage from climate change is insignificant in the absence of PP
S_3 = damage from climate change is severe in the absence of PP, and PP is ineffective

If action according to the precautionary principle is put in, and this policy turns out effective, the damage, *D* is prevented. *C* and *D* are measured in units of social welfare, and thus reflect properties of the welfare function, such as risk aversion.

Everything else equal, we can compare the social welfare generated by the two policies in each state of nature.

$$\begin{aligned} W(PP, S_1) &= -C \\ W(NA, S_1) &= -D \\ W(PP, S_2) &= -C \qquad etc. \end{aligned} \tag{5.2}$$

This calculation gives the following table (all numbers in absolute values):

Strategy:	States:		
	S_1	S_2	S_3
PP	*C*	*C*	*C+D*
NA	*D*	*0*	*D*

When the probabilities are unknown, one might consider a uniform probability distribution. Then, all states are given equal weights, and thus considered equally possible ($p(S_i)=1/3$, i=1,2,3). The expected social welfare of each of the two policies is then:

$$\begin{aligned} EW(PP, s) &= -\left(C + \frac{1}{3}D\right) \\ EW(NA, s) &= -\frac{2}{3}D \end{aligned} \tag{5.3}$$

The calculation shows that, given a uniform probability distribution, the expected social welfare will be higher under remedial action (PP). The example shows that the planner should choose the precautionary principle, according to the criterion of expected social welfare maximization, if and only if:

$$D > 3C \tag{5.4}$$

Which is fulfilled according to the assumption made about the relative size of costs.

Another usual solution, when the probabilities are unknown, is to apply a symmetric bell-shaped probability function. In our example, this means that you give a small probability to state 1, an equally small to state 3, and a bigger to state 2. Consider for instance the case where the probability of S_2 is 1/2 ($p(S_2)=1/2$), and the two other sates are equally likely ($p(S_1)= p(S_3)=1/4$). In this situation one should choose action according to the precautionary principle only if:

$$D > 4C \tag{5.5}$$

Thus, no action will be preferred under this probability distribution. This seems sensible considering that the heaviest weight is put on the case were climate change does not occur.

If the planner has reason to believe that state 1 is more likely to occur than the two other states, the conclusion is modified. Consider for instance the case where the probability of S_1 is 2/3 ($p(S_1)=2/3$), and the two other sates are equally likely ($p(S_2)= p(S_3)=1/6$). Expected social welfare is then:

$$\begin{aligned} EW(PP,s) &= -\left(C + \frac{1}{6}D\right) \\ EW(NA,s) &= -\frac{5}{6}D \end{aligned} \tag{5.6}$$

This probability distribution also implies selecting the precautionary principle if the damage from climate change in the absence of this policy is sufficiently larger than the costs of adapting it. Here, however, D must be but one and a half times the size of C:

$$D > \frac{3}{2}C \tag{5.7}$$

Thus, the relative restriction for choosing action is halved compared to the restriction under a uniform probability distribution. This also seems sensible considering that the heaviest weight is put on the case were climate change occur and the policy is effective.

These calculations illustrates the obvious point that decisions according to maximizing expected welfare, is highly dependent on the probability distribution and the relative magnitude of costs. Furthermore it reflects full confidence in our subjective probability believes underlying s. This is not completely realistic, due to the complex uncertainty structure of the climate problem.

Expected utility theory is very useful for dealing with situations where probabilities and possible outcomes are within the normal range of human experience. The climate problem is not within this range. We simply do not have the experience to calculate proper weights to aggregate utility over states. Non-probabilistic decision criteria, to which we now turn, might therefor be more suitable.

5.2 Minimax

The minimax criterion says that one should maximize the welfare in the worst possible case. Essentially it allows loss-aversion to become infinite:

$$\max_{A}\left\{\min_{s} W\left(A, s\right)\right\} \tag{5.8}$$

This is a very conservative or cautious criterion, and it might be looked upon as an extreme version of the precautionary principle, but this is not always the case.

Adopting the precautionary principle implies acting to avoid unfavorable events, regardless of their likelihood. Let us try to analyze the rationale of this policy decision as a minimax strategy by looking at the example derived in the previous subsection:

Strategy:	States:			Max Loss:
	S_1	S_2	S_3	
PP	*C*	*C*	*C+D*	*C+D*
NA	*D*	*0*	*D*	*D*

Considering the possibility of policy ineffectiveness, the worst possible outcome is to implement a costly precautionary principle strategy that fails to avert severe damages. However, if we ignore the third state, where the precautionary principle strategy is ineffective, we can see that the minimax criterion, implies always selecting action according to the precautionary principle. Thus, unless there is no uncertainty regarding the policy effectiveness, the precautionary principle can not be rationalized as the appropriate minimax strategy in this game against nature[4].

5.3 Generalized minimax / maximax

This criterion can be formalized as follows:

$$\max_{A}\left\{\alpha \min_{s} W(A,s) + (1-\alpha)\max_{s} W(A,s)\right\} \tag{5.9}$$

This is a non-probabilistic decision criterion, which says that one should choose the level of abatement so as to maximize a weighed average of the social welfare in the best and the worst situation, with respect to the uncertain parameter. The size of α can be interpreted as if it reflects the planner's beliefs about the likelihood of facing the worst case in the future. This is

[4] This conclusion is of course dependent on the belief that *C* is negative. If not, that is if the secondary benefits from PP outweighs the implementation costs, PP is always superior (See section 6).

then a simplification of the expected welfare criterion. We can either find the worst and the best case with appurtenant subjective probabilities, or we can divide all possible outcomes into two groups; the bad outcomes and the better outcomes. With this angle of incidence, the interpretation of α will be the possibility of realizing one of the bad outcomes.

Using our very simplified example, the planner is to choose the maximum of:

$$\begin{aligned} PP&: \quad -(\alpha D + C) \\ NA&: \quad -\alpha D \end{aligned} \tag{5.10}$$

Thus, as with the minimax criterion, no action will be preferred, unless there is no uncertainty regarding the policy effectiveness[4]. This result holds regardless of the size of α. If, however, we know for certain that the precautionary principle strategy will be effective, we will choose this policy as long as we believe D to be twice the size of C:

$$D > 2C \tag{5.11}$$

which holds by assumption.

5.4 Limited degree of confidence

This criterion is as follows:

$$\max_A \left\{ \gamma E_s W(A,s) + (1-\gamma) \min_s W(A,s) \right\} \tag{5.12}$$

Here the planner maximizes a weighed sum of the expected social welfare criterion and the minimax criterion. The $\gamma \in [0,1]$, measures the planner's degree of confidence in the probability distribution underlying EW. For the case of full confidence, $\gamma = 1$, he will use the expected social welfare criterion, whereas under complete uncertainty, $\gamma = 0$, the minimax decision rule arises. Thus, $1-\gamma$ denotes the degree of uncertainty. In this interpretation, uncertainty is simply the counterpart of confidence in the probabilistic assessment underlying the expected social welfare calculation (Stigum 1990, Eichberger & Spaniels1998).

Again, using the simple example with a uniform probability distribution, the Planner is to choose the maximum of:

$$\begin{aligned} PP&: \quad -\left[C + \left(1-\gamma\frac{2}{3}\right) D \right] \\ NA&: \quad -\left(1-\gamma\frac{1}{3}\right) D \end{aligned} \tag{5.13}$$

showing that equally possible states favor the precautionary principal strategy when:

$$D > \frac{1}{\gamma} 3C \tag{5.14}$$

The restriction on the magnitude of damage from climate change in the absence of remedial action, relative to the costs of adapting this policy, is scaled with the degree of confidence in the probability distribution. We have that the higher the degree of confidence, the lower the restriction. For the case of full confidence, $\gamma = 1$, we have exactly the expected utility restriction (equation (5.4)), and the planner will choose action, but when the degree of confidence is weaker, $\gamma < 1$, no action will be preferred. Then the minimax criterion, which is reflecting extreme fear of the worst case, dominates the expected welfare criterion completely.

The symmetric bell-shaped probability distribution yields the restriction: Select the precautionary principle if:

$$D > \frac{1}{\gamma} 4C \tag{5.15}$$

Given our assumption about the relative size of C and D, the planner chooses the precautionary principle if $\gamma > \frac{4}{3}$, which, by assumption, never is fulfilled. Thus, the symmetric probability distribution goes in favor of no action, which is natural, considering the probability distribution.

However, considering the probability distribution $p(S_1)=2/3$, and $p(S_2)= p(S_3)=1/6$, the planner will select the precautionary principle policy if :

$$D > \frac{1}{\gamma} \frac{3}{2} C \tag{5.16}$$

Full confidence, again, gives the expected utility restriction (equation (5.7)), but sufficiently low confidence in the probability distribution gives no action. If the damage from climate change is three times the costs of action, the planner will choose the policy according to the precautionary principle if $\gamma > \frac{1}{2}$.

5.5 Minimax regret

Minimax regret (or loss) minimizes the difference between the best that could happen and what actually happens (Fishburn 1987). The planner seeks to minimize his regrets for not having, in hindsight, made the superior choice. This could be interpreted as choosing the option, in which the planner believes future generations would least regret:

$$\min_A \left\{ \max_s \left[W\left(A^*(s), s\right) - W\left(A, s\right) \right] \right\} \tag{5.17}$$

When s is known, then $A^*(s)$ would be the optimal choice of A. The criterion then says that one should minimize the maximal regret. In other words, you choose the policy that makes the maximal error as small as possible. This might be a way for the politicians to minimize the ex post critique.

Minimax regret may be particularly relevant when policies serve a dual purpose. In many instances, actions to combat local environmental problems protect biodiversity, and so forth, will simultaneously have a desirable impact on global warming. Conversely, policies aimed at combating an enhanced greenhouse effect, such as reducing forms of air pollution, caused by using fossil fuels, and the lowering of clear-felling of rainforests, will also often help alleviate local environmental problems. These dual-purpose policies are particularly attractive if there is a significant chance that either a greenhouse problem will not occur or that human preventive action will be ineffective. This is illustrated in the game against nature, previously analyzed. The minimax regret cost matrix for this game will be:

Strategy:	States:			Max Regret:
	S_1	S_2	S_3	
PP	0	C	C	C
NA	D-C	0	0	D-C

Thus, the maximum regret incurs either when the precautionary principle policy is ineffective, or when the planner finds it unnecessary, ex post. When applying the policy of no action, the maximum regret is the loss from not implementing the precautionary principle when doing so could have prevented large damages. When comparing these regrets, we see that the precautionary principle should be implemented on the basis of the minimax regret criterion if $C<D-C$ or equivalently:

$$D > 2C \tag{5.18}$$

which holds by assumption.

5.6 Safety first

Another way of showing precaution is by lowering the probability of the future welfare being too low. Here are two alternatives:

$$\min_A \left\{ \Pr\left[W\left(A, s\right) \le k \right] \right\} \tag{5.19}$$

$$\max_A \left\{ E_s W\left(A, s\right) \right\} \text{ s.t } \left\{ \Pr\left[W\left(A, s\right) \le k \right] \le \beta \right\} \tag{5.20}$$

The first alternative, a probabilistic non-expected utility criterion (equation (5.19), minimizes the probability of the welfare being less than some constant, *k*. The second alternative (equation (5.20) maximizes the expected social welfare, subject to a constraint, which says that the probability of the welfare being less than *k*, should be less than β.

In addition to the problems discussed, regarding expected social welfare and the uncertainty structure of the climate problem, the safety first criteria pose questions about how to determine *k* and β. What determines the acceptable size of β, the probability of the future welfare being less than *k*? How likely can it be? This question might depend on the size of *k*. How low a welfare can we accept? This is again dependent on whether or not *k* measures the welfare on average. If so, is this a weighed average, and how then are the weighs determined? And how disaggregated is it? Is *k* a weighed sum of each group, land or region? However, even if *k* and β is determined, facing the uncertainty, how can the planner know that a certain policy decision will satisfy the constraints?

Another safety first approach is to have constraints on the welfare of the worst off group, land or region. One example might be:

$$\max_A\left\{E_sW(A,s)\right\} \text{ s.t } \left\{\Pr\left[\min_i W_i(A,s)\le k\right]\le\beta\right\} \qquad (5.21)$$

Here the planner is supposed to maximize the expected future social welfare subject to the probability of the welfare of the worst off, being less than β. If β is equal to zero, the constraint can be interpreted as a floor. If the size *k* is chosen properly, this criterion will ensure a sustainable development. Loosely, a sustainable development demands each generation to not use more than their legitimate part of the world's resources (Asheim 1993). If one or several generations have too high a consumption, or their consumption generates too much pollution, this undermines the consumption possibilities of later generations. If so, the later generations might not be able to reach the social welfare level *k*, and the criterion is violated.

6 Conclusions

The above discussion has shown that the preferred policy choice is very much dependent on the choice of decision criterion. Furthermore it is dependent on the magnitude of costs and the framing: on how states of nature is defined, and on the subjective beliefs about the probability distribution of states. Considering the fact that the example is constructed in such a way that one should expect a policy of action to be chosen in preference to a policy of no action, the conclusions are somewhat surprisingly divided.

In the example examined, the maximizing expected welfare criterion favors action according to the precautionary principle when the probability distribution is uniform or skewed in favor of state 1. When a symmetric bellshaped probability distribution is applied, however, no action is preferred.

The minimax criterion and the generalized minimax / maximax criterion never favors action as long as there are uncertainty regarding the effectiveness of the remedial policy, unless $-C>0$ of course. This might be the case if the secondary benefits from climate change remedial action are greater than the costs.

Policies to reduce greenhouse gas emissions by reducing the burning of fossil fuels will also reduce other emissions. They may also reduce road traffic. It is well accepted that the pollution of these other emissions and the effects from road traffic, such as accidents and noise, are responsible for substantial external costs. It is the reduction of these various negative external effects, pursuant on policies to abate greenhouse gas emissions, which are the secondary benefits of such policies (Ekins, 1996, Aunan et al. 1998). If the secondary benefits are sufficiently large, the costs of implementing the abatement policy will be outweighed. If this is the case, we will have $-C>0$ and the remedial policy will always be preferred, regardless of the policies' effect on climate change, and regardless of the criterion chosen.

Using the criterion of limited degree of confidence, the uniform probability distribution suggests action only if the planner has complete confidence in the underlying probability distribution. Using the skewed distribution, remedial action is preferred only if $\gamma>1/2$. The symmetric bell-shaped distribution, however, always points in the direction of no action.

The minimax regret criterion always favors action under the assumptions given in the example examined. Thus, action according to the precautionary principle cannot be rationalized as a minimax strategy in this game against nature. However, applying the notion of regret changes this conclusion.

It is thus the maximizing expected social welfare, the limited degree of confidence and the minimax regret criteria that yields the desired conclusion of action. The former two also has the property that when the greatest weight is given the state where climate change does not occur (the symmetric bell-shaped distribution), no action is preferred.

Carefully constructed experiments, however, have shown that people tend to place greater weight on low-probability extreme events than the expected utility theory predicts (Kahnemann & Tversky 1979, Chrisholm & Clarke 1993). This implies that if the welfare function is utilitarian, in the sense that the social preferences are the sum of the individuals subjective preferences, it will place too much weight on extreme events. This functional form might not be adequate, however, when approaching the climate problem. We do not know the preferences of future generations. Furthermore, even if people, as individuals place higher weights on low-probability extreme events, this does not mean that the planner ought to do the same. That is an entirely different discussion.

The theory of expected utility requires that an ordering can represent individual's choice among actions. This means that the decider must have a complete overview of possible states of nature and their probabilities. Given the uncertainty structure of the climate problem, this is a very strong assumption. Yet, expected utility or welfare may provide an adequate framework for explaining and predicting social choice in uncertain situations. When using the other criteria, similar information problems must be faced.

The class of safety first criteria, for instance, has similar information problems, in addition to the problems of deciding upon the strictness of restrictions. The idea of safeguarding the worst off from too low a level of welfare seems sensible. However, in extreme cases, this might mean that one should make the majority much worse off to benefit the worst off marginally.

Using minimax when deciding is reflecting extreme fear of the worst case. There is a problem, however, to know the nature of the worst case. What is the worst that can happen as a consequence of human made climate change? Another problem is that the worst case can be so bad that the policy decision becomes irrelevant. The worst case can be a catastrophe of such dimensions that a decision between doing this or that might not have significant influence over the outcome.

Applying the notion of regret to the minimax criterion gives more desired conclusions. On the one hand, the minimax regret rule is criticized on the grounds that regret consists of "crying over spilt milk", which the proverb says is not the way to optimize. On the other hand, the minimax rule, sensibly gives some weight to the relationship between the costs of implementing a precautionary policy and the loss of doing nothing when the damages caused by global warming turns out large. This holds even when there is uncertainty about whether or not the precautionary policy will be effective (Chrisholm & Clarke 1993). However, it might not be too easy to define and measure the regrets.

We have seen that despite the simplifying assumptions of having a benevolent planner who is both supranational and supragenerational, and having a well-defined intergenerational welfare function, there are still problems remaining. Thus, when balancing the environmental irreversibility, the risk of an acceleration of mitigation policies if the worst happens, with the investment irreversibility, the risk of over-cautious policies, the challenge should not be to find the best policy today for the next hundred years, but to select a prudent strategy and to adjust it over time in the light of new information (IPCC 1995). Selecting such a strategy is a major challenge for the policymakers of today.

7 References

Aunan, K., G. Pátsay, H.A. Aaheim, H.M. Seip (1998). "Health and environmental benefits from air pollution reductions in Hungary*". The science of the Total Environment* 212 (245-268).

Arrow, K.J. (1965). "Aspects of The Theory of Risk-Bearing ". Yrjö Jahnssons Lectures, Helsinki, Finland.

Asheim, G.B. (1997). "Individual and Collective Time-Consistency*". Review of Economic Studies* 64 (427-443).

Asheim, G.B. (1993). "Hvor bærer det hen? Utvikling av teori for en bærekraftig økonomi". *Sosialøkonomen* nr.4.

Bretteville, C. & H.A. Aaheim (1999). "Abatement of Greenhouse Gas Emissions under Uncertainty" (preliminary title). Mimeo, CICERO.

Chrisholm, A.H. & H.R. Clark (1993). "Natural Resource Management and the Precautionary Principle". Ch. 7 in Fair Principles for Sustainable Development; E. Dommen (Ed.). Brookfield (New horizons in environmental economics).

Colgazier, E.W. (1991). "Scientific Uncertainties, Public Policy, and Global Warming: How Sure is Sure Enough?" *Policy Studies Journal*, Vol. 19, No. 2, (61-72).

Eichberger, J. & W. Spaniels (1998). "Liquidity and Uncertainty: Banks or Asset Markets?" Mimeo, University of Saarland, Germany.

Ekins, P. (1996). "How large a carbon tax is justified by the secondary benefits of CO_2 abatement?" *Resource and Energy Economics* 18 (161-187).

Elster, J. (1989). *Nuts and Bolts*. Cambridge University Press, Cambridge

Fishburn, P.C. (1987)."Utility Theory and Decision Theory". The New Palgrave - A Dictionary of Economics, The Macmillian Press Limited, London and Basingstoke (779-783)

Harding, R. & L. Fisher (1992). "The Precautionary Principle". Paper for Ecopolitics VI Conference 1992.

Kahneman, D. & A. Tversky (1979). "Prospect Theory: An Analysis of Decision under Risk". *Econometrica* Vol. 47, No. 2

Knight, F.H. (1971). *Risk, Uncertainty, and Profit*. The University of Chicago Press, Chicago.

Kolstad, C.D. (1994). "George Bush versus Al Gore". *Energy Policy* Vol. 22, No. 9 (771-778).

Machina, M.J. (1989). "Dynamic Consistency and Non-Expected Utility Models of Choice Under Uncertainty". *Journal of Economic Literature*. Vol. XXVIII, December, (1622-1668)

Malnes, R. (1997). *Filosofi for statsvitere*. Tano Aschehough, Oslo.

O'Donoghue, T. & M. Rabin (1999). "Choice and Procastination". Mimeo, Cornell University and University of California, Berkeley.

Rawls, J. (1971). *A Theory of Justice*. Harward University Press, Cambridge Ma

Ringius, L. (1999). "Differentiation, Leaders, and Fairness: Negotiating Climate Commitments in the European Community". *International Negotiation* 4 (133-166)

Schelling, T.C. (1993?). " Intergenerational Discounting". Mimeo, School of Public Affairs, University of Maryland, USA

Stigum, B. (1990). *Toward a Formal Science of Economics*. The MIT Press, Cambridge, Ma.

Tol, R.S. (1995). "The Damage Costs of Climate Change. Toward more Comprehensive Calculations". *Environmental and Resource Economics* 5 (353-374)

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