“Risk management strategies under climatic uncertainties”

AUTHORS	Urs Steiner Brandt
ARTICLE INFO	Urs Steiner Brandt (2012). Risk management strategies under climatic uncertainties. *Environmental Economics*, *3*(1)
RELEASED ON	Friday, 20 April 2012
JOURNAL	"Environmental Economics"
FOUNDER	LLC “Consulting Publishing Company “Business Perspectives”

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
0	0	0

© The author(s) 2025. This publication is an open access article.

BUSINESS PERSPECTIVES

businessperspectives.org

Environmental Economics, Volume 3, Issue 1, 2012

Urs Steiner Brandt (Denmark)

Risk management strategies under climatic uncertainties

Abstract

This paper is concerned with the issues of risk assessment, risk management, and risk communication in the context of risks posed by anthropogenic climate change. The particular focus of this paper is on the problems of designing and implementing risk management strategies in situations with extreme risk and uncertainty, and how to design possible solutions to such problems. For example, these problems might include those caused by the impossibility of disentangling natural from human-caused changes in the climatic system, or problems caused by only relying on best guess estimates as inputs into the decision-making process.

Keywords: climate policies under uncertainties, risk management, natural variations.
JEL Classification: Q30, H41.

Introduction

This paper analyses two different ways that uncertainties pose severe problems for decision makers in the climate change field. The first case involves the problem of natural variations in the climate system that might hide the real influence of mankind on the climate. The invisibility of climate change makes it difficult to implement climate policies, and this can, in the end, turn out to be very costly. The second issue is that, in the climate change field, using best guess estimates (as presented by the Independent Police Complaints Commission (IPCC)) severely underestimates true damage costs in the presence of extreme events. As a consequence, if policymakers base their decision making on such estimates, non-optimal choices are to be expected.

Although the two cases are distinct, they have in common that policymakers have difficulties in implementing effective climate policies. This paper proposes two decision criteria that will be suitable for making better decisions than the best guess criterion. Moreover, for both cases, the need for properly risk communication is stressed as a tool for reducing the significance of these problems.

The heart of risk assessment is disentangling how different types of risk enter various levels of the system in different ways, and hence, enabling the development of a more rigorous regulation system to address these complexities. Little work has been done, however, under situations where it is difficult to disentangle natural fluctuations from man-made climate components. One exemption is new research that suggests that natural variations are so far being underestimated. Christiansen et al. (2009) re-analyzed the famous Mann et al.'s (1998) study of pre-industrial temperature development (the hockey stick model) and found that, by using state-of-the-art climate models, that natural variation is much larger than expected.

To carry forward the primary point of the first part of this paper, we use a case study of (hypothetical) winter temperature development in the 21st century in Denmark (as a proxy for temperature development in the North Atlantic area) to provide an example of how the presence of a human-induced climate component on top of natural variation might result in periods of large temperature shifts (with access to the smooth projections of the IPCC, 2007). Such rapid variations in regional temperature might (though presumably not very likely) result in changes that have severe negative regional, or even global, impacts[1].

The problem with the presence of natural variation is that, in certain cases, periods of rapid temperature increases are followed by periods of no change or even periods of temporary falls in average temperatures. This is particularly a problem if public opinion is shaped largely by observable events, which several studies suggest is the case (see e.g., Blada and Shackley, 2008). This raises the notion of political feasibility. Political feasibility is the idea that whether or not a particular policy can be implemented depends on different political, economic, and informational constraints. One such constraint is that the 'visibility' of the problem must be large, and the level of uncertainty should be low, in order for an effective climate policy to be easily implemented.

As a consequence, in periods of no observed increase in the average temperature, effective climate policies are difficult to implement. Moreover, it can then be expected that such a period will be followed by a period of large temperature increases, when no appropriate policy measures will be in place. This can create a serious problem, either because effective

© Urs Steiner Brandt, 2012.

---

[1] One main problem in this is the potential existence of tipping points in the Earth system on a regional scale, as is discussed in several papers (Lenton et al, 2007; Krieger et al., 2007). In Lenton et al. (2007), tipping points are defined as follows: "For components of the Earth system that are at least subcontinental in scale (~ 1000km) they are tipping elements if: the parameters controlling the system can be transparently combined into a single control, and there exists a critical value of this control from which a small perturbation leads to a qualitative change in a crucial feature in the system, after some observation time". A reasonable hypothesis is that not only absolute temperature change matters, but also the temperature change per time unit. For example, the faster a change occurs, the more likely it is that a tipping point will be reached. Such extreme events constitute a considerable risk in the area of climate change.

climate policies take time in order to be implemented, or because such policies will be excessively expensive to implement.

In the second part of the paper, we analyze the potential shortcomings of employing only best guess estimates as proxies for real expected damage costs. This will, in real-life, be problematic if marginal damage costs are increasing with changes in temperature, or if, under a given emissions scenario, the resulting changes in temperature follow an extreme distribution.

There are now two sources of problems, which might act together quite well. On the one hand, decision makers are not given adequate information (or will at least not have sufficient information) to act cautiously on the basis of real risk. On the other hand, if natural variations blur "true" development in the severity of climate change issues, there will be no pressure from voters to implement more stringent climate policies.

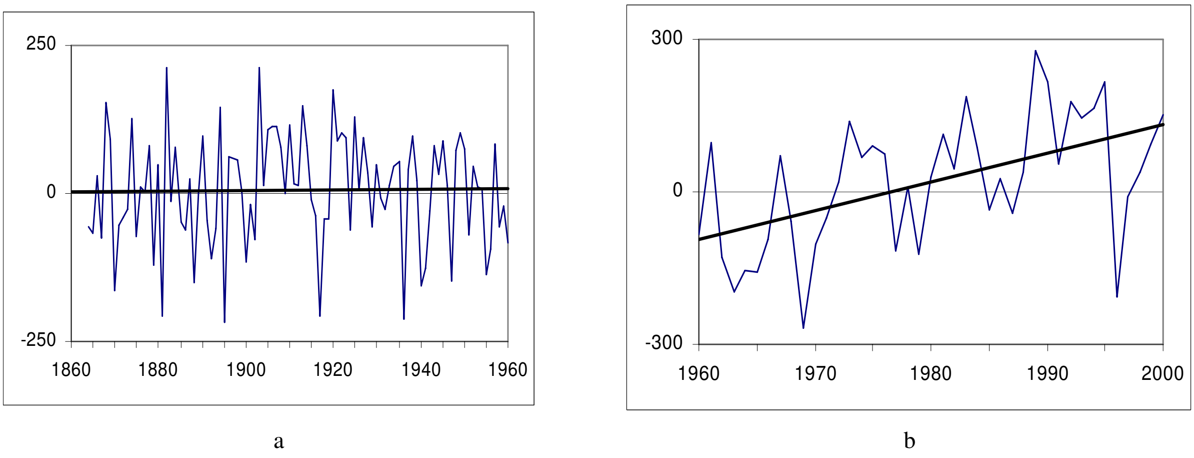
One basic message is that low probability, highly negative impacts should not be ignored, but rather incorporated into the decision process. On basis of this message, this paper considers a number of possible decision criteria that can be used for exactly this purpose. Two distinct decision criteria are presented that, in essence, call for implementing a balanced climate policy that reduces the risk from climate change without compromising economic performance. This is only possible if no information is ignored.

Better risk communication is also a way to overcome these shortcomings. According to Bolin (2005), it is of basic importance to recognize that we shall never be able to predict very well the details of regional and, in particular, local characteristics of a human-induced climate change. On the other hand, this fact must not paralyze us and prevent us from adopting sensible preventive actions. Robust knowledge about central scientific issues must be brought home more convincingly.

1. The implications of natural variations

1.1. The NAO and its relation to climate change. Consider the "rapid" increase in the water temperature in the North Sea and the problems of disentangling the main causes of this phenomenon. The temperature in the sea around Denmark has increased up to 2 degrees over the past two decades. Each year, tropical fish and plankton move north at a speed of 50 km per year. Already now, new species of fish have arrived in Danish seas (like mackerel, mullet, and anchovy), while at the same time, plaice and cod are disappearing. Over the past 25 years, the catch of cod in the Danish part of the North Sea has fallen from 60,000 to 4,000 tonnes, while the number of fishers has fallen from 15,000 to under 6,000[1].

However, uncertainty remains as to what has caused these increases in water temperature. The newest estimates of global temperature changes state that a temperature increase of about 0.6 degrees has been seen over the last century. Aside from the global trend, there are also regional climatic patterns that determine the mean temperature in Northwest Europe (in particular, the North Atlantic Oscillation; NAO). The NAO is a climatic phenomenon in the North Atlantic Ocean comprised of fluctuations in the difference of sea-level pressures between the Icelandic Low and the Azores high. A high NAO is typically associated with westerly winds blowing across the Atlantic, which brings moist air into Europe. In years when westerly winds are strong, summers are cool, winters are mild, and rain is frequent. If westerly winds are suppressed, the temperature is more extreme in the summer and winter, leading to *heat waves*, deep freezes, and reduced rainfall.



a

b

Source: Danish Meteorological Office.
Notes: Bold lines indicate trend.

Fig. 1. Developments in NAO

Figures 1(a-c) show how the NAO has fluctuated. From 1864 to 1960, there is no significant trend, while from 1960 to 2000 there is a significant positive trend. As Figure 1b shows, longer periods with significant negative trends can also be identified, e.g., from 1949 to 1969.

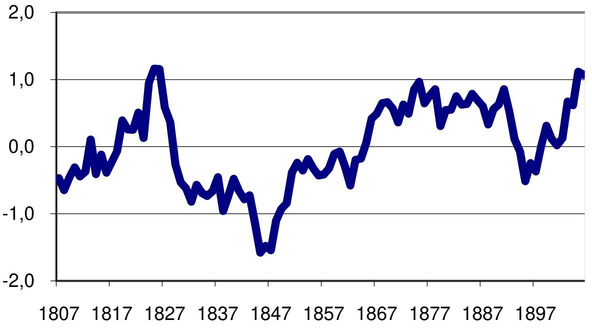
The exact cause of this change in the behavior of the NAO is not well understood, and there are only very weakly established linkages to general climate change. If the NAO has a very long amplitude (e.g., related to periodic changes in the pattern of major currents), then a possible return to "a normal" level can be expected, which would imply that the water temperature in the North sea might remain constant (or even fall) in the short run even while global mean temperature is steadily increasing. Looking at the NAO over the last 140 years, longer periods of both positive and negative trends can be identified. As the 30 and 40 year moving average curves indicate, the NAO exhibits a long amplitude of 70 to 80 years).

1.2. Natural and human caused climate change. Looking more deeply into the issue of natural variations, Figure 2 consists of 110 years of a historic temperature series for winter temperatures in Denmark, and depicts a 10-year moving average. The figure shows natural fluctuations in the climate caused by variations in sea currents, variations in the activity of the sun, and eventual chaotic processes in the climate system. The time series is chosen such that it does not contain any man-made climate component.

In particular, the large drop in the temperature between 1825 and 1845 and the increases in the temperature between 1847 and 1852 and between 1895 and 1905 deserve attention. These periods indicate how large the natural variation can be at a minimum (nothing precludes, of course, that even larger changes are possible).

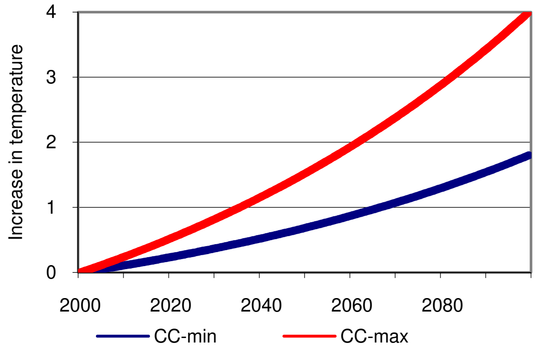
On top of this, we show the IPCC forecast for the next 100 years for man-induced climate change (Figure 3), including the lowest and the highest estimates fitted exponentially, as man-made emissions of GHG gasses are likely to increase over the millennium.

Figure 4 conveys the idea derived from combining these two figures. One possible scenario is shown where, in 40 years, 10-year average winter temperatures are most likely lower than today, even after adding the man-made climate component. However, from that point on, temperatures rise rapidly, between three to four degrees in the next 40 years and again at the end of the period, implying a total increase over 100 years between 3.4-5.5 degrees.



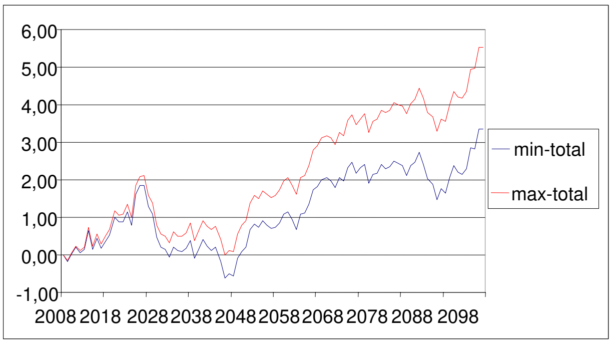
Source: Danish Meteorological office.

Fig. 2. 10 years moving average, winter temperature, Denmark (1807-1907)



Source: Danish Meteorological office.

Fig. 3. IPCC forecast for next 100 years



Source: Danish Meteorological office.

Fig. 4. Constructed temperature series

Obviously, this represents only one of many possible scenarios. That the possibility of man-made and natural variations interacting positively at some point, however, is not unlikely. From this exercise, two distinct questions emerge. Is natural viability making things worse and, secondly, if temperatures are unlikely to increase over decades (regionally), will this affect the possibilities of implementing effective policies?

1.3. The implication of natural variation on feasible policies. Once the need for policies (risk management strategies) is detected, the next question concerns the sometimes overlooked problems of political feasibility. According to Webber (1985), political feasibility can be defined as the relative likelihood that a policy proposal or alternative, and a variety of modifications to that alternative, can be adopted and implemented in such a way that the policy problem is solved or mitigated. Skotvin (2007) argues that political feasibility can be looked at as function of certain constraints. She defines three major categories of constraints, constraints related to cost-benefit distribution, constraints related to the distribution of power, and constraints related to the institutional setting. Finally, Brandt (2000) argues that several characteristics of the problem at hand determine the likelihood of successfully implementing an effective climate policy. Figure 5 shows the main ideas presented in Brandt (2000).

Three important variables that shape the political feasibility of implementing effective climate policies are the level of knowledge, the willingness to pay for reductions, and the costs and benefits of the problem, as all of these variables serve as important inputs in the decision-making process.

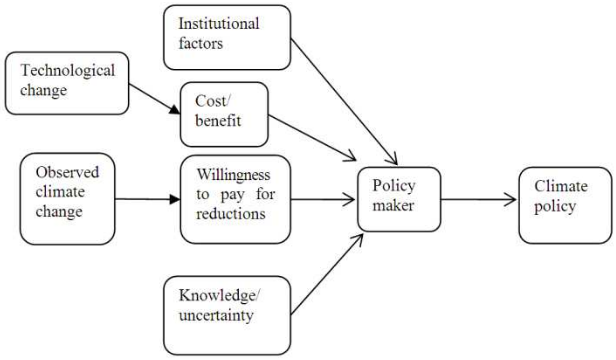


Fig. 5. The possibility of implementing policy, constraints on political feasibility

These variables are themselves dependent on other variables. In particular, relevant to the current paper is the link between observed climate change and voters' willingness to pay for (or accept) costly reductions in greenhouse gas emissions[1]. In periods with no temperature changes, or even temporary decreases, many will doubt that there exists man-made climate change (which will give fuel to the climate scepticism industry, in the same way that temporarily large increases give fuel to the climate hype industry). Therefore, in years with large observed damages this willingness increases, while in years with few damaging events, this willingness decreases.

Natural variations will inevitably imply that periods where temperatures are increasing will be present and that this will be elevated by man-made climate change. Extreme events like tipping points could now be reached, or, by initiating positive feedback mechanisms, temporarily changes could have permanent (or unstoppable) effects. Large shocks to the system push the population below minimum threshold population survival levels. One problem is the problem of adaptation. It takes time for nature to adapt to changes. While a 2-4 degree change in temperature over 100 years might imply that adaptation is possible (by, e.g., migration), a 4-degree increase in temperature over 35 years will imply a major stress on nature. Furthermore, the economic costs of adaptation (e.g., in agriculture or forestry) might also be huge, especially when temperature changes are so large over so short time period.

In sum, after a period of stable temperatures, the willingness to reduce emissions is low, and a country (or society) is unprepared (relatively) to cope with large sudden changes. Given the time-span necessary to change, for example, a country's energy supply system, and given that climate change is a stock pollutant, no measures that reduce the effects can be implemented with the necessary fast response.

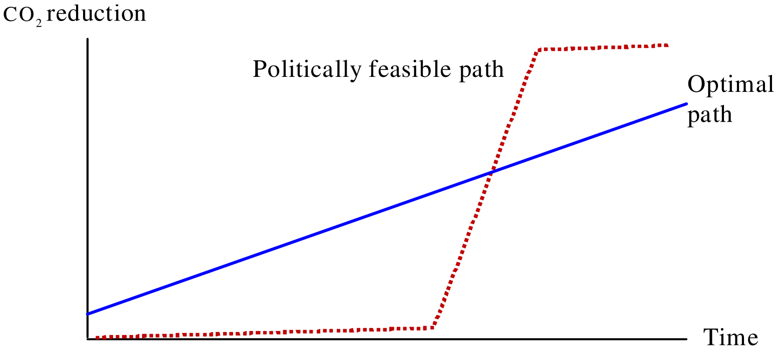


Fig. 6. Divergence between optimal and feasible paths

---

[1] The other factor shown in the figure is the importance of technological changes, which, according to IPCC 2007, is the most important determinant behind the costs of climate policies.

We summarize the findings of this section in Figure 6, where an example is shown of apolitically feasible path that is much more expensive than the optimal path, when abatement costs are marginally increasing (That is, it is much more costly to make much reduction over a short period than it is to have a smoother reduction policy). It might not, however, achieve the same level of protection. Therefore, adding natural fluctuations to man-induced changes presents an even larger challenge to decision makers.

2. The distribution of damages and changes in temperature

In this section, we look more generally at the choice of climate policies. The problem that the decision maker faces can be formulated as choosing a climate policy (CP) that minimizes the net costs (NC) of the climate problem. If the expected reduction costs $(E[RC])$ and the expected damage costs $(E[DC])$ can be calculated, then the optimal climate policy can be derived from:

$$\min_{CP} E[NC] = E[RC] + E[DC].$$

In the following, it is assumed that the expected damages are a function of the increase in temperature[1]. The expected damages can be calculated as:

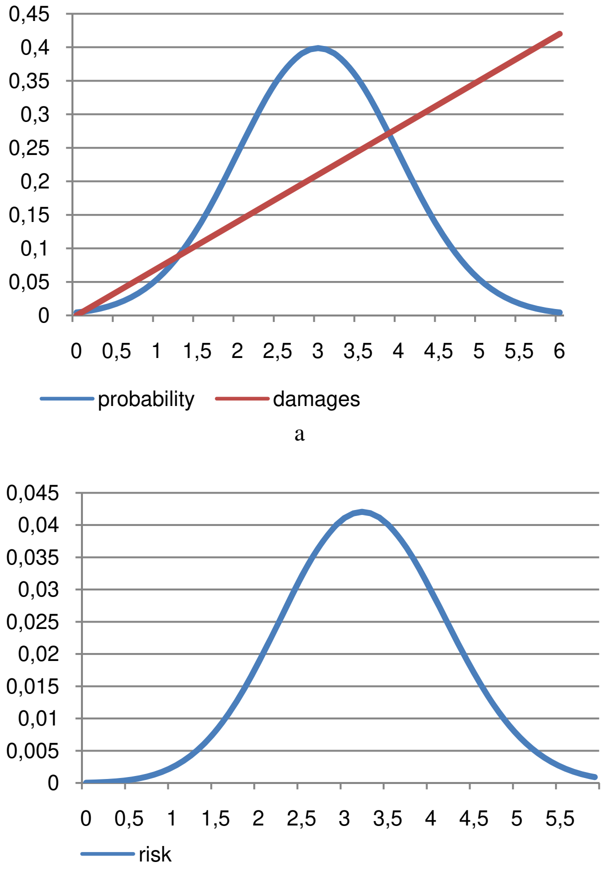
$$E[DC(CP,T)] =$$

$$= \int_{T=T^{low}(CP)}^{T^{high}(CP)} [f(T)\cdot[\int_{DC^{low}(T')}^{DC^{high}(T')} f(DC(T'))\cdot DC(T')]]dT.$$

For a given increase in the temperature, *T'*, it is necessary to know the potential damage costs and the distribution function over the damages in order to calculate the resulting expected damage. This is true as well in a defined interval, $DC(T') \in [DC^{low}(T'), DC^{high}(T')]$, where the boundaries of the interval can be defined for political or scientific reasons (this explains the inner integral). To calculate the total expected damages of a climate policy, we need to know the possible changes in temperature described in the interval $T(CP) \in [T^{low}(CP), T^{high}(CP)]$, and the distribution of probabilities over this interval, $f(T')$.

Therefore, if, for a given development in the temperature *T'*, we have a probability distribution over damages, it is possible to calculate the expected damages for each possible change in the temperature. And, therefore (at least in principle), if we have a probability distribution over the possible temperature changes for a given climate policy, we can calculate the total expected damages from a given climate policy.

Now, the question is under what circumstances can we circumvent these troublesome and informational demanding calculations and instead use an approximation that is more simple, e.g., by only looking at the most likely developments in the temperature and then take the associated most likely damage, an approach that will be referred to as the best guess method.



a

b

Fig. 7. Changes in the temperature are normally distributed and damages are linear increasing

In the first example, shown in Figure 7, we have a normally distributed development in the temperature, and damages are linearly increasing (furthermore, we could also introduce a normal distribution over damages, where the variance does not vary with temperature changes). In this case, it follows that the damage at the point at the most likely change in temperature is equal to the expected damages[2].

---

[1] E.g., looking 20, 50, or 100 years ahead and seeing (calculating), for a given increase in temperature over this time span, the damages this results in. The damages could be discounted, such that they represent the net present value of the sum of all damages, or only the damages in the final year of observation. Both ways will highlight the main point of this section.

[2] Since the damage function is only defined for non-negative changes in the temperature, we must have that the relevant temperature interval is symmetric around the mean. In the figure, the mean is 3 and the change in temperature focused on is between 0 and 6.

Figure 7b shows the attached distribution of risk, calculated as:

Risk = Probability that an event occurs x *The consequences if this event occurs.*

The area beneath the risk curve shows the expected damages. In this particular case, where the risk is normally distributed and with its highest points at the most likely temperature change, it is fully acceptable to use the best guess method.

The best guess method implies, however, serious problems when applied to climate change. The first problem is that damages most likely are not linearly increasing, but rather marginally increasing. Second, temperature development is most likely skewed to the right, while the distribution of damages is not symmetric around the mean. We look into each of these issues below.

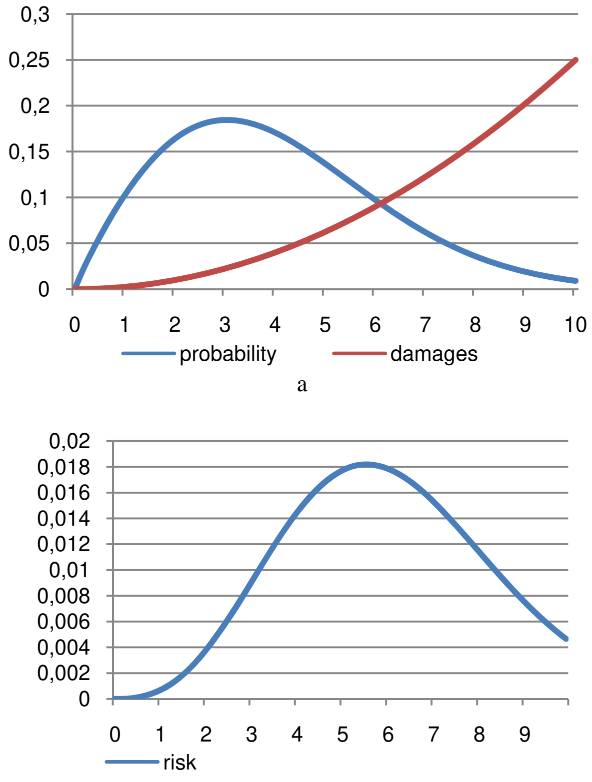
IPCC (2007a) mentions several impacts that are either growing (more than linearly) with increasing temperature, or will first arise after the temperature has reached a certain level. Such damages are expected to come from the negative impacts on water, ecosystems, food, coasts, and health. As the temperature rises, these impacts either grow in extent or severity. According to the IPCC (2007a, page 10), an increase in temperature of 1-5 degrees will imply a growing likelihood that hundreds of millions of people will be exposed to increased water stress, coastal flooding, extinction of species, and an increasing burden from malnutrition (to name just a few effects).

The presence of abrupt or even irreversible changes also depends on the severity of the change in temperature. This could be due to so-called low probability, high impact events like the partial loss of ice sheets on polar land, and/or the thermal expansion of seawater over very long time scales, which could imply meters of sea level rise and major changes in coastlines and inundation of low-lying areas, with the greatest effects in river deltas and low-lying areas. The likelihood of such a scenario is clearly positively related to changes in temperature.

The second shortcoming of the best guess approach is that, for climate change, the distribution of temperature is not normally distributed, but rather stretches out to the right, as can be seen below.

The Stern Review (Stern, 2007, Part I: Climate Change – Our Approach, page 8) presents the newest estimates of climate sensitivity, where climate sensitivity is sensitivity of the climate to a doubling of CO_2 content in the atmosphere in equilibrium, as compared to pre-industrial levels. The review shows that eleven recent studies suggest only between 0% and 2% chance that the climate sensitivity is less than 1°C, and that between a 2% and 20% chance exists that climate sensitivity is greater than 5°C. These sensitivities imply that there is up to a one-in-five chance that the world will experience a warming in excess of 3°C above pre-industrial levels, even if greenhouse gas concentrations were stabilized at today's level of 430 ppm CO_2e. Note further, that all estimates (to a varying degree) are skewed to the right, with tails stretching out to 10 degrees, even though the most likely temperature increase is approximately 2-3.5 degrees.

To see an example of the importance of these shortcomings, assume instead that the increase in temperature is distributed under an extreme distribution, and furthermore that the damages are convexly increasing as the temperature changes. Let the increases in the temperature follow a Weibull distribution, as shown in Figure 8. In the example, the distribution has its maximum at $T = 3^1$. Furthermore, the damages are given as $DC(T) = 0,0025T^2$.



a

b

Fig. 8. Development in the temperature are stretched to the right and damages are convex

The expected damages are approximately 0.49 (if looking at the interval for the increase in temperature

---

[1] The curve is calculated in Excel using the following specifications: Weibull (T; 1,9; 4,5).

between 0 to 10 degrees). If we take the best guess approach, then our estimate of the damage is only 0.023, which accounts for only 4.6 % of the expected damages. Note that the risk is at its maximum at nearly 6 degrees. If the best guess is chosen on basis of the most likely development in the temperature, most of the present risk is simply ignored.

Hence, in this (extreme) example, the best guess approach seriously underestimates the true expected damage, and in this case is not an appropriate input into the decision-making process.

The final source of error in applying the best guess approach to the climate issue is that the damages are seldom overestimates, but instead are most often underestimated. It has already been mentioned that sea levels could rise more than expected and that the damages connected with such an event are marginally increasing.

More generally, *"Understanding of low-probability/high-impact events and the cumulative impacts s of sequences of smaller events, which is required for risk-based approaches to decision-making, is generally limited"* (IPCC, 2007b, p. 73) and *"Partial loss of ice sheets on polar land could imply meters of sea level rise, major changes in coastlines and inundation of low-lying areas, with greatest effects in river deltas and low-lying islands. Such changes are projected to occur over millennial time scales, but more rapid sea level rise on century time scales cannot be excluded"* (IPCC, 2007a, p. 13).

Finally, various thresholds exist and, when surpassing these, potentially large damages can be expected. The probability of such events occurring and the impacts if they occur are most likely positively related to the increase in temperatures.

Figure 9 shows an example of all three possibilities. Basing these estimates of damages only on the most likely event will result in a massive bias in the estimates of damages (or, rather, a much too low estimate of the damages).

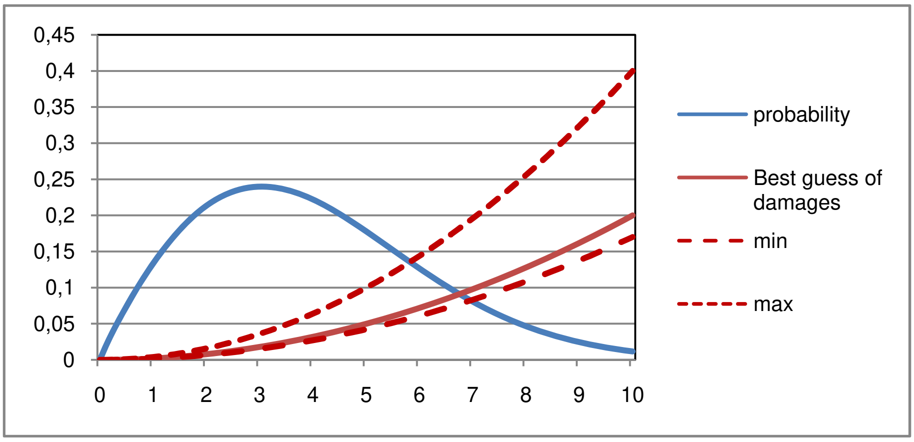


Fig. 9. An example where the expected damages are much larger than the best guess damage

The focus in this section has been on the damage side, even though there are also huge uncertainties attached to the reduction cost side, and there seems not to be an equal bias in using best guess estimates. One possibility is that the reduction costs turn out to be catastrophically high, which does not exist. The worst case scenario can be described as a situation with low technological progress, leaving cleaner technologies non-competitive, and where there is a large public resistance against reduction (adding to political costs). This will likely be the occurrence under any best case scenario (or any situation in between) where progress in technological development makes the transition to a carbon free society smooth and at low costs.

The opinions of the IPCC on the matter of incorporating extreme events emerge from this quote: *"The equilibrium climate sensitivity is a measure of the climate system response to sustained radiative forcing. It is likely to be in the range 2 to 4.5°C with a best estimate of about 3°C, and is very unlikely to be less than 1.5°C. Values substantially higher than 4.5°C cannot be excluded, but agreement of models with observations is not as good for those values. Water vapour changes represent the largest feedback affecting climate sensitivity and are now better understood than in the TAR. Cloud feedbacks remain the largest source of uncertainty"* (IPCC, 2007, p. 2).

From the various IPCC scenarios, it is evident that the IPCC does not report extreme temperature events, as seen in Table 1.

Therefore, a large portion of the risk will be ignored by the IPCC, which implies a bias in the decision-making process. Compare this with the following statement by Henry (2006):

"If a decision-maker a priori rejects as 'scientifically unsound' any act which is not unambiguous, that means that he sticks to the maximization of a von Neumann-Morgenstern expected utility on the set of acts which are scientifically unambiguous. In doing so,

he neglects a large array of scientific information which, however uncertain, might be reliable and decisive. In short, we can say that 'optimizing on the set of acts which are scientifically unambiguous is not optimal" (Henry, 2006, p. 10).

Table 1. IPCC scenarios for projected global surface average temperature increase in the end of the 21st century

IPCC scenario	Best guess	Likely low	Likely high
B1	1,8	1,1	2,9
A1T	2,4	1,4	3,8
B2	2,4	1,4	3,8
A1B	2,8	1,7	4,4
A2	3,4	2	5,4
A1F1	4	2,4	6,4
Average	2,8	3,1	

Source: IPCC (2007).

Henry argues that this is exactly what happened in the case of BSE. The question here was whether BSE and CJD (Creutzfeldt-Jacob disease) could be linked. Experiments conducted on mice showed that a link might exist: According to Henry (2006), the foundations were by no means complete. A piece of non-probabilistic uncertain science was, however, sufficiently convincing to scientifically support the decision to bar English beef from being consumed in the European Union.

Instead of simply ignoring extreme uncertain events, one should consider some risk management strategies that could deal with such cases by explicitly considering risk. Such a view supports the arguments provided in the Stern Review that one should not ignore apart of the problem that is not properly understood (as is argued in the IPCC report).

3. An example of a biological tipping point

An illustrative example is useful to show how the two above problems can create serious problems for optimal decisions. Some renewable resources have a critical stock level, below which the resource cannot recover without serious economic losses to the related harvesting industry. That is, an action that causes the resource to collapse has an (almost) irreversible effect on this stock. Such a collapse and even extinction of fish resources is a serious problem, and is documented in, e.g., Hutchings and Reynolds (2004), who report that data for more than 230 marine fish populations reveal a medium reduction of 83% in population size from historical levels. Uncertainty, however, prevails in the reasons for this observation. Myers et al. (1997) argue that two main hypothesis have been put forward as possible explanations. One is that high fish mortality is due to high harvesting levels, and the other is (temporary) unfavourable (environmental) conditions.

Hilborn et al. (2001) claim that political and economic motives reinforce the problem of reductions in stock size given uncertainty. The reason is that fishermen stress that the cause is not overfishing but rather temporarily unfavorable conditions, and that the policymakers, afraid of implementing costly policies that might ex-post turn out incorrect, support the fishermen's demands for higher quotas (a behavior known as the "minimax regret" strategy). The relation to political feasibility is evident. In periods of no or only small climate changes (or changes in temperatures), it might be very difficult to implement fishery policies that have larger safety margins or, more simply, imply smaller catch levels on basis of climate arguments. Hilborn et al. (2001) further argue that while this may appear to be an adequate response to short-term socioeconomic pressure, it may only result in a more acute crisis later on, which is exactly the point made in section 2.

To illustrate this, assume that there exists uncertainty about the true, exact level of the threshold, as well asuncertainty about how future climate change will affect the growth rate of the resource. Consider the following situation: q_1 is the catch level in period 1, while $S_2(q_1^*)$ is the resulting stock in period 2. The stock in period 2 depends on first-period catches as shown in Figure 9, as indicated by the curve labelled "growth". There is uncertainty attached to this relationship, indicated by the shaded area about the curve. $\overline{S}_2$ is the threshold stock level, below which the resource will simply collapse. The shaded areas represent some confidence interval of the uncertainty about the exact size. The curves could represent best guess estimates. Given the best guess, and without climate change, the optimal level of catch is q_1^*, where the probability of collapse is small, but not zero (even though, according to the best guess, the stock remains well above the threshold).

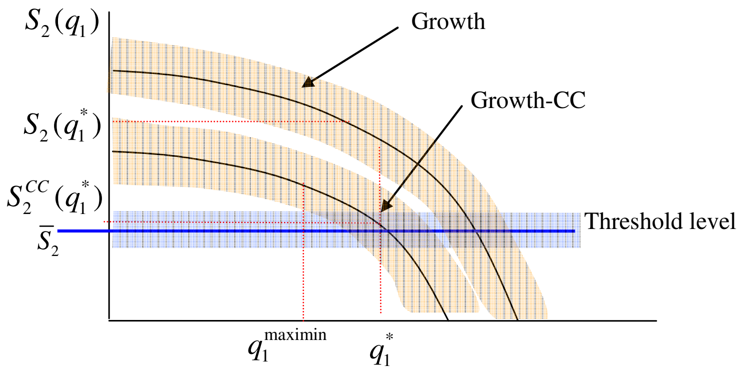


Fig. 10. Growth rate and safety level of a renewable resource, with a possibility of a climatic change in the growth function

Now consider a sudden shift in the growth function caused by rapid temperature changes, but assume this to be badly understood, such that the same fisheries policy is used (or that there is a time-lag in the policy process). For policy q_1^*, there is a considerably risk that the resource will collapse, as seen in Figure 10, where Growth-CC is the growth rate given climate change, even though the best guess estimates still indicate that the stock might not collapse.

That is, given the time lag in the possibility of making policy changes, the problem of pressure from stakeholders (here the fishermen), and the input from the science community about best guesses, the policy can be expected to remain at q_1^*, which constitutes a large probability of the fishery's collapse.

A policy that would take into account that collapse should not occur, and would reduce harvesting levels to $q_1^{maximin}$, though this level is infeasible in the short run. Once the seriousness of the problem is understood, it might simply be too late, or it would be extremely costly to rebuild an economically viable stock. Note that a change in temperature could equally shift the threshold level, resulting in the same qualitative results.

This simple analysis shows that (1) if policies only consider the most likely situations, a large part of the risk is ignored; (2) if the uncertainty is increased (e.g., in the possible size of the threshold), then if policies are locked in a 'business as usual' framework, a larger probability of collapse can be expected; (3) if it takes time to adjust policies (due to the political feasibility argument), then if a change in temperatures comes around quickly, a large risk of collapse can again be expected; (4) the worst case here is a combination of 1-3, where, on the one hand, large risk components are ignored, and policies do not take into account possibly abrupt changes in environmental variables. Polices take time to change in a period of no change in temperature followed by a period of rapid increases in temperature.

4. Decision criteria

The point of departure in this section is that the decision maker faces a decision problem that can be described by the basis of feasible actions (climate policies), the possible consequences of each action, and the possibility of attaching a probability to each consequence (or when a probability distribution over consequences is available). If all such information is available, then the decision maker can calculate the expected value of each action and choose the policy that minimizes total costs from the pollution problem.

When considering decision making under uncertainty, then at least some of the above information is not available to the decision maker at the time when the decision must be made (this could either be when not all consequences are known or when it is not possible to attach probabilities to consequences, or both). In such cases, it is not possible to calculate expected values, and the decision maker must employ other decision criteria.

Maximizing the expected value (or minimizing expected damage) has the advantage of incorporating all available information, and therefore also the information about small probability large consequence events. When all necessary information is not available, then we must use other criteria. We have already seen that best guess criteria seriously underestimate true risk. In order to avoid this, it is necessary to find a criterion that does not have this shortcoming.

Another criterion is the "maximin" criterion that chooses an action that implies the smallest possible damage. The maximin does not require that probabilities over consequences are known, and needs only that it be possible to rank consequences from the worst to the best. The maximin can be interpreted as a strategy of minimizing the risk from the pollution problem, but since it focuses exclusively on avoiding worst cases, it leaves out any consideration of possibilities. The maximin is a criterion that focuses exclusively on avoiding worst cases, without needing the knowledge of how likely these worst cases are. For example, in the case of a collapsing stock, let q_1^{maximin} be the level of optimal choice given that the maximin is chosen (in this case, the worst case would be that the stock collapses, since all future profit opportunities vanish)[1].

Therefore, what is needed is a criterion that combines the elements of maximizing welfare and reducing risk. Consider a situation where the decision maker has full information about a part of the problem, but less than full information about the rest of the problem. The first part contains the areas where the understanding of underlying mechanisms is good (that is, the scenarios for future consequences are well described both in terms of impact and probability of occurrence). The second part contains all the remaining areas, where understanding is not as good, and where there is uncertainty about consequences or the probability of their occurrence is unknown or very uncertain. Given such a set-up, consider now the following more general decision criterion, inspired by Bretteville (1999), as a possible operationalization of the reflections of Henry (2006):

$$\text{Max}_A\{\gamma E_{S^1} W(A,S^1)+(1-\gamma)\min_{S^2} W(A,S^2)\}. \qquad (1)$$

Let S^1 be the known states of nature (that is, known with respect to the likelihood of occurrence and resulting consequences, if they occur) while S^2 are those states of nature that are more uncertain (e.g., situations where either the probabilities are unknown or the consequences are not (fully or partially) understood. A is the set of policy alternatives and W is the welfare function. $\text{Max}_A E_{S^1} W(A,S^1)$ states that the planner chooses to maximize the expected utility over S^1. $\text{Max}_A \min_{S^2} W(A,S^2)$ states that the planner chooses the maximin over S^2 (chooses the action, where the highest possible loss is minimized)[2].

Note that the IPCC sets $\gamma = 1$, while Henry argues that it must be set below 1.

The decision criterion now states that an action should be chosen that maximizes a weighted sum of two distinct decision criteria, the maximization of the expected utility criterion, and the maximin criterion. $\gamma \in [0,1]$ is a politically determined parameter that measures the weight assigned to incompletely understood events[3].

In essence, the equation describes a criterion that balances risk management (or risk reduction) with the economic dimension. A society fundamentally faces a trade-off between security and welfare. If too much welfare is chosen today, this reduces the future possibilities for achieving a higher level of security. The damages and the implied costs reduce future economic possibilities, and security cannot be afforded. On the other hand, if too much security is chosen today, this will also reduce future possibilities (implying less growth to pay for future reductions and, at the same time, have economic growth).By applying this criterion, the decision maker is better equipped to deal with the climate change issue.

Applying equation (1), we get $q^{RM} = \gamma \cdot q^* + (1-\gamma)\cdot q^{\text{maximin}}$, where q^{RM} is the harvest level chosen by the risk management strategy. Here, the larger γ, the smaller the harvest level. More generally, we can calculate the implicit function $q^{RM} = q^{RM}(\gamma)$, such that the chosen harvest level is fully determined by γ.

Another way of looking at risk management is to say the decision maker should choose the action that maximizes welfare, under that condition that we should most be exposed to the risk at a pre-determined probability level. Consider the following criterion:

$$\max_A\{E_s W(A,S)\}\ s.t.\ \{\text{pr}\left[W(A,S)\le k\right]\le \beta\}. \qquad (2)$$

This criterion says that the decision maker should choose apolicy, A, that maximizes the expected social welfare, subject to a constraint, which states that the probability of the welfare being less than k should be less than β.

In the case of a collapsing resource, we can translate this to a predetermination of how large a probability of collapse a society should be willing to accept (which will very likely be larger than zero). In a more general application, this amounts to deciding how large a risk a society should be exposed to. This again has the virtue of considering risk more explicitly in the decision-making process, instead of simply neglecting it.

Conclusion

This paper deals with several challenges that the presence of extreme risks, natural variation, and ‘real uncertainties’ pose for the possibilities of designing adequate risk management strategies and imple-

---

[1] Note, however, that the maximin need not imply that the probability of collapse is reduced to zero, since this might imply a very bad outcome for harvesters, and the worst-case costs of such a policy might be larger than the worst-case costs of accepting some probability of collapse.

[2] Note that the worst consequence of each action is not known, and this decision criterion cannot be applied.

[3] Since it is most likely that extreme events can be described by S^2, this corresponds to judging how large a weight should be assigned to extreme events.

mentation. It is, however, not always possible to reduce all uncertainty. That is, the answer to uncertainty is not always increased research, but rather effective ways of communicating risk to the public. In situations with extreme risks, it must be understood that the share of risk that is ignored by ignoring such unlikely events is large. Better risk communication is a way to overcome these shortcomings: conveying this to policymakers and the public is essential.

According to Bolin (2005), it is of basic importance to recognize that we shall never be able to predict very well the details of regional and, in particular, local characteristics of human-induced climate. On the other hand, this fact must not paralyze us and prevent sensible actions to be undertaken. Therefore, robust knowledge about central scientific issues must be brought home more convincingly. As a consequence, in situations with real uncertainties, or situations where uncertainty is not likely to be resolved even when intensified scientific research is conducted, one strategy is to convey this uncertainty more effectively to policymakers and the public.

References

1. Bolin, B. (2007). Four Professional Perspectives, The view of a scientist in the process. In Sjostrom, G. (ed.): 'Facilitation of the climate talks, dealing with stumbling blocks, Climate Change Negotiations: A Guide to resolving disputes and facilitating multilateral cooperation' forthcoming at Earthscan.
2. Brandt, U.S. 'Determination of politically feasible solutions to international environmental problems', Economic Discussion Paper No 1/2000 University of Southern Denmark.
3. Brandt, U.S. (2007). 'The probability of collapsing of a renewable resource under climatic uncertainties', paper presented at the 2007 EAFE in Iceland.
4. Bretteville, C. (1999). 'Decision Criteria under Uncertainty and the Climate Problem', CICERO working paper 1999: 10, Olso.
5. Christiansen, B., T. Schmith, and P. Thejll (2009). 'A Surrogate Ensemble Study of Climate Reconstruction Methods: Stochasticity and Robustness', *Journal of Climate*, 22, pp. 951-976.
6. Mann, M.E., R.S. Bradley and M.K. Hughes (1998). Global-scale Temperature pattern and Climate Forcing over the Past Six Centuries', *Nature*, 392, pp. 779-787.
7. Myers, R.A., Hutchings, J.A and N.J. Barrowman (1997). 'Why do Fish Stock Collapse? The Example of Cod in Atlantic Canada', *Ecological applications*, 7, pp. 91-106.
8. Hutchings, J.A. and J.D. Reynolds (2004). 'Marine Fish Population Collapses: Consequences for Recovery and Extinction Risk', *BioScience*, 4, pp. 297-309.
9. Henry, C. (2006). 'Decision-Making under Scientific, Political and Economic Uncertainty', Working Paper, EcolePolytechnique, Paris.
10. Hilborn, R., J.-J. Maquire, A.M. Perma and A.A. Rosenberg (2001). 'The Precautionary Approach and Risk Management: Can they Increase the Probability of Successes in Fishery Management', *Canadian Journal of Fisheries and Aquatic Sciences*, 58, pp. 99-107.
11. Krieger, E., W. Hall, H. Held, R. Dawson and H.J. Schellhuber (2007). 'Imprecise Probabilities of Crossing Tipping Points in the Earth System From Experts.
12. Lenton, T.M., H held, E. Krieger, J.W. Hall, W. Lucht, S. Rahmstorf and H.J. Schellhuber (2007). 'Tipping Elements in the Earth System, Proceedings of the National Academy Science, USA.
13. IPCC (2007). IPCC WG1 AR4 Report (http://ipcc-wg1.ucar.edu/wg1/wg1-report.html).
14. IPCC (2007a): IPCC Synthesis Report, Climate Change 2007: summery for policymakers, http://www.ipcc.ch/ ipccreports/ar4-syr.htm.
15. Stern Review on the Economics of Climate Change, http://www.hm-treasury.gov.uk/independ-ent_reviews/stern_review_economics_climate_change/sternreview_index.cfm.
16. Skotvin, T. (2007). Exploring the notion of political feasibility in environmental policy', CICERO working paper 2007: 03, University of Oslo.
17. Webber, D.J. (1985). 'Analyzing political feasibility: political scientists' unique contribution to political analysis', *Policy Studies Journal*, 14, pp. 545-553.
18. Tol, R.S.J. (2012). 'On the uncertainty about the total ecoomic impact on climate change', *Environmetnal and Resource Economics*, Publihed Online 26 Februar 2012.