GLOBAL WARMING AND FISHERIES: THOUGHTS ON A SENSIBLE RESPONSE

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ABSTRACT

Atmospheric measurements show that so-called greenhouse gases have been accumulating in the Earth's atmosphere for well over a century. There are strong indications that human activity plays a significant role in this process. One consequence of the accumulation of greenhouse gases is thought to be an increase in global temperatures above what would otherwise be the case. Projections on the basis of large scale climatic models suggest that this warming could be as much as 2-6°C during the 21st Century. Temperature changes of this magnitude would almost certainly lead to a significant alteration in the geographical pattern of economic conditions and conceivably cause long term harm.

Among the economic activities that may be significantly affected by global warming are the world's fisheries. If global warming leads to a change in oceanographic conditions, which seems likely, the biological growth, geographical range and behaviour of fish stocks may also change. This could have a deep impact on fisheries as an economic production activity especially locally and possibly also globally. The problem, however, is that this is about as much as we know. We know very little about the direction let alone the magnitude of the impact of global warming on fisheries both regionally and globally. A recent large scale study of the impact of global warming on Arctic and sub-Arctic fisheries suggests that here the impact is more likely to be beneficial than detrimental, but the uncertainty is great.

Thus, the world's nations are faced with a difficult decision problem. In very broad terms the choice is between two options: The first is to embark right away on a program of significantly reducing the emission of greenhouse gases. This option is very costly but may generate benefits later. The latter option is to postpone all drastic actions until the facts of the matter have become clearer and less uncertain. This saves outlays now but can result in additional costs later. This decision problem is the main subject of the paper. The paper shows that even if global warming were a certainty and could actually be significantly counteracted by reduced greenhouse gas emissions, this would not necessarily be the best policy. The uncertainty about global warming and the human impact on it serves to render this option even less attractive. The paper shows that the most sensible option may well be to postpone action until more reliable information becomes available.

Keywords: Global warming, fisheries and global warming, sensible response to global warming, global warming and uncertainty

INTRODUCTION

Measurements indicate that various types of so-called greenhouse gases (GHGs) have been accumulating in the Earth's atmosphere for well over a century. There is evidence that human activities, especially various types of combustion, play a significant part in this process. Projections with the help of large scale climate models indicate that the continued accumulation of GHGs could lead to global atmospheric warming of some 2-6°C by the end of the current century (IPCC 2001 and 2005). Moreover, this process of global warming could continue during the 22th Century if the accumulation of GHGs doesn't halt.

There is little doubt that temperature changes of this magnitude would have a noticeable impact on the economic and ecological conditions around the world. Irrespective of whether these changes are for the better or worse, they would at the minimum require costly adjustments and very probably some alteration in the geographical location of economic activity and habitation. Appealing to this, and numerous other less well founded arguments, there has been strong political pressure for global reduction in the emission of GHGs. The Kyoto Protocol constitutes a response to this pressure.

Fisheries are among the economic activities likely to be affected by global warming. Fish stocks depend very much on oceanographic conditions; water temperatures, up-welling, mixing of water masses, water salinity, water oxygenation, currents, ice formation and melting and so on. Global warming of the magnitude discussed is likely to affect these conditions. Thus, quite apart from the overall impact on the size and productivity of global fish stocks, their geographical concentration is quite likely to be altered. Moreover, the process of ecosystem adjustments ands readjustments to these new conditions is likely to be complicated and drawn-out in time. This particular implication of global warming has only recently come under scientific scrutiny. Some early results are found in ACIA 2005 chapter 13 and Hannesson et al 2006.

In this paper, however, we will not have much to say about the impact on fisheries specifically. Our main concern will be nature of the decision problem. The essence of this problem is as follows: There is a prospect of global warming. This, if it happens, will affect economic conditions, including fisheries, but in uncertain ways. One factor in global warming is human emissions and GHGs. Reducing these emissions may reduce global warming but by a very uncertain magnitude and a long time down the road. Moreover, reducing GHG emissions significantly is also known to be quite costly. Given these circumstances; what is the most sensible policy? In fact, in this paper, we will not have very much to say about the best policy — this depends on the empirical data of the problem. What we will do is to highlight some basic aspects of the decision problem, aspects that will logically have to be taken into account if the most sensible policy is to be discovered. Needless to say, the same basic aspects also apply in the fisheries part of the problem. Thus, when a fisheries dependent country or region or even a fishing industry formulates its policy regarding the prospect global warming it should do so on the basis of exactly the same considerations.

This paper is broadly organized as follows: We begin by discussion the basic decision problem. This is fundamentally quite complicated. From this we go on to consider a very simple version of the basic problem which has the advantage of being easily tractable while retaining certain crucial elements of the basic problem. This simplified problem, therefore, is helpful to highlight the key aspects of the problem. Finally, the main results of the paper are briefly discussed.

THE BASIC DECISION PROBLEM

We are faced with a typical dynamic decision problem under uncertainty. There is a probability of altered conditions, in this case global warming, which may negatively affect benefits. Available is a set of actions, in this case reduced emissions of GHGs, which may reduce global warming. Both the benefits and the costs of the actions are uncertain and both materialize over time.

The actions involve investments. These are investments in equipment, technology and human capital to reduce emissions and harness alternative energy sources. Obviously, many of these investments are specialized and less than perfectly reversible. The same applies to institutional structures, such as international contracts, national laws and regulations, monitoring and enforcement systems, research programs, education programs and so on set up to systematically reduce GHG emissions. These social structures are very often highly inflexible and durable and, therefore, tend to keep going long after their purpose has disappeared.

The evolution of time complicates the situation further. Costs and benefits of actions are experienced over a long time and, in the case of global warming, the costs have to be suffered long before any benefits appear. Even more importantly, as time passes certain uncertainties diminish. For instance it will become clearer whether global warming is taking place or not and at the rate predicted. Thus, with time we can be more confident about the validity of global warming theories. Moreover, research, which is another decision variable, will tend to reduce uncertainty about the various aspects, causes and consequences of global warming as and the costs and benefits of countervailing measures.

The above describes a well-known class of decision problems often referred to as irreversible investment problem under uncertainty (see e.g. Dixit and Pindyck 1994). These problems are usually technically demanding and the solutions, when they can be found, complicated and difficult to understand.

To illustrate the basic nature of the basic problem it is helpful to present it more formally. Let a (possibly a vector) denote actions undertaken to reduce global warming. Write the net benefits of these actions as

$$NB(a,z)=B(a,z) - C(a,z),$$

where $B(a,z)$ denotes the benefits and $C(a,z)$ the costs of the action a when the state of the environment e.g. the temperature, accumulated GHGs and other variables are represented by z.

The present value of a given time path of actions, $\{a\}$, say, is:

(1) $$V(\{a\}) = \int_0^\infty W(B(a(t), z(t)) - C(a(t), z(t)), z(t)) \cdot e^{-r \cdot t} dt \,,$$

where *W*(.,.), a function and both net benefits of the action and the state of the environment, measures social welfare at each point of time, *t*, and *r* is the rate of time discount.

As already discussed, the environmental variables in (1) are subject to considerable uncertainty. This uncertainty may be described by the appropriate stochastic processes. For that propose so-called Wiener processes are convenient (see e.g. Dixit and Pindyck 1994). An example of a generalized Wiener process for *z* is:

(2) $dz = g(z,a,t)\cdot dt + h(z,a,t)\cdot du,$ where $du = \phi\cdot\sqrt{dt},\ \phi \sim N(0,1)$.

Similar expression could be used to describe the uncertainty concerning the benefits, *B*, and costs, *C*.

The objective is to select a time path for *a*, so that the expectation of *V*({*a*}) in (1) is maximized subject to the Wiener process (2) and other constraints. As already mentioned, it is in general very hard to find and characterize the solution to this kind of a problem (see e.g. Dixit and Pindyck 1994 and Pindyck 2000). In this paper we aim much lower. We only seek to highlight certain key aspects of the problem and its solution. For that purpose it is sufficient to consider a very simplified version of the basic problem.

THE SIMPLIFIED PROBLEM

Consider two states of nature. The first involves global warming with negative effect on production, the ecosystem and living standards. This state, in other words, is similar to the one heralded by those that warn against global warming. Let us refer to this state as S-1. The second state is not negative — either global warming does not occur or its consequences are not detrimental. This state we refer to as S-2. Let us assume that the estimated probability of S-1 is *q* and the probability of S-2 (1-*q*).

For actions there are also two options. The first, referred to as A -1, is to counteract global warming with reduction in GHG emissions. Option A-1 entails costs, *C*. The other option, A-2, is to do nothing. That option doesn't cost anything.

Now let *B*(*i*,*j*) represent social benefits when the state of nature is *i* and option *j* is selected. The possible outcomes can thus be collected in the following table:

Table 1
Possible outcomes

	State of nature	
Actions	S-1 Probability: *q*	S-2 Probability: 1-*q*
A-1	*B*(1,1)-*C*	*B*(2,1)-*C*
A-2	*B*(1,2)	*B*(2,2)

According to Table 1 the expected value of the two options for action are:

$EV(1) = q \cdot B(1,1)+(1-q) \cdot B(2,1)-C,$

$EV(2) = q \cdot B(1,2)+(1-q) \cdot B(2,2),$

where $EV(1)$ and $EV(2)$ represent the expected value of actions 1 and 2, respectively. The expected difference between the two options therefore is:

$$(3) \quad \Delta EV \equiv EV(1)-EV(2) = q \cdot \Delta B(1) - C + (1-q)\, \Delta B(2)$$

where $\Delta B(1) \equiv B(1,1)-B(1,2)$ and $\Delta B(2) \equiv B(2,1)-B(2,2)$. The first difference, $\Delta B(1)$, measures the net benefits of selecting action A-1 rather than A-2, if global warming with negative impacts, i.e. S-1 occurs. In accordance with those who push for reduction in GHG emissions I assume that this difference is positive. The latter difference, $\Delta B(2)$, measures the net benefits of selecting action A-1 rather than A-2, if the state of nature is S-2, i.e. either global warming or its negative impacts do not materialize. It appears save to assume that this difference cannot be positive, i.e., $\Delta B(2) \le 0$. This essentially means that if there is no global warming, reduction in the emission of GHGs is not going to increase welfare.

This simple formulation immediately leads us to the first important conclusion.

Result 1
Even if the expected gain from the action to reduce emissions is greater than the cost of doing so, i.e. $q \cdot \Delta B(1)$-C>0, it may not be sensible to undertake that action.

This result follows immediately from (3). Due to the term $(1-q)\, \Delta B(2)$, it is only when $q=1$, i.e. global warming with negative consequences is going to happen with certainty will $q \cdot \Delta B(1)$-C>0 be sufficient to render A-1 counteracting actions optimal.

Now, ΔEV can be either positive or negative. If it is negative there is obviously no sense in selecting action A-1. But, is in necessarily a good idea to select A-1 when $\Delta EV>0$? The answer is no. The reason is that if A-1 is selected, the other option, A-2, is lost, at least partially. Selecting A-1 is accompanied by imperfectly reversible investments in physical and human capital, technology and institutions. If it turns out, some years down the road, that the state of nature is actually S-2, i.e. global warming is not occurring or it doesn't have negative consequences, then option A-2 is no longer available. Of course, at this point, we might be able to revise our strategy and revert to A-2, but we would still be saddled with the imperfectly irreversible investments associated with A-1. Thus, the previous A-2 would not be available in the same economic form as before. If, on the other hand, A-2, is selected, nothing irreversible happens. At the beginning of the next period, it will be possible to choose between options A-1 and A-2 again, most likely on the basis of added information and knowledge. The only possible cost is a delay of one period.

As Dixit and Pindyck (1994) have explained to us, the ability to choose between action A-1 and A-2 may be regarded as option. This option has a certain value exactly like the more familiar financial option. By initially selecting A-1 this particular option is lost at least partially as discussed above. Thus choosing A-1 is accompanied with a cost, option value cost, which must be subtracted from the from the expected benefits of selecting A-1. If that is done, it may turn out to be unwise to select A-1 even when the ΔEV in expression (3) is positive.

Let us now examine this more closely. In order to highlight the key features of the problem we make three simplifying assumptions. First let $B(2,1)=B(1,2)=B(2,2)=0$. This, simplification is essentially to simplify the algebra and (although hardly empirically tenable) seems to me analytically innocuous. With this simplification, Table 1 may be rewritten as Table 2.

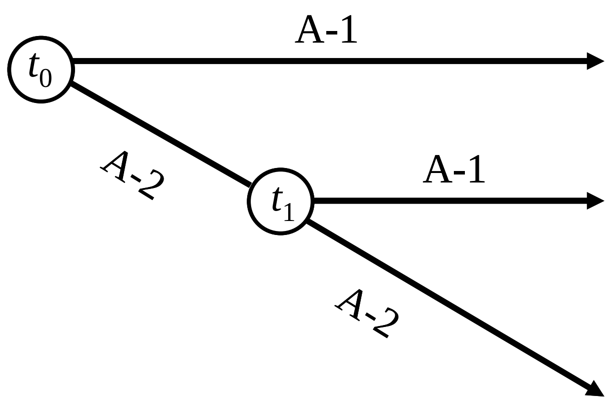
Table 2
Possible outcomes: Simplification

	States of nature	
Actions	S-1 Probability $=q$	S-2 Probability$=1-q$
A-1	$B-C$	$-C$
A-2	0	0

Second, we assume that instead of continuous time, we can only choose actions at two time points, the current time, $t_0=0$, and at some later time, t_1. With respect to global warming it seems reasonable to assume that t_1 is within a few years time.

The third assumption has to do with the representation of irreversibility. At t_0 it is possible to choose between actions A-1 and A-2. We assume that if A-1 is selected, i.e. GHG emissions reductions are undertaken, this policy can not be reversed for a considerable time which is longer than t_1. So, in this case the option to choose an action at t_1 is lost. Only some time later will this option reappear. By this formulation I attempt to represent in a simple manner the imperfectly reversibility of the A-1 option discussed above. If, on the other hand, A-2 is selected at time t_0, there is no irreversibility. The option to choose actions appears again at t_1. What has been lost is only time. The resulting decision tree is illustrated in Figure 1

Figure 1
Global warming: Decision tree



Seen from time t_0, there is obviously a certain probability of making the correct decision at the decision node t_1 (assuming, of course, that a choice can be made then). Correct decision, of course, is to select A-1 if global warming occurs and A-2 if it doesn't. Denote this probability by s. The probability of making the wrong decision at time t_1 then are 1-s. The combined probability of the various outcomes following a decision at t_1 are therefore as described in Table 3.

Table 3
Probability of outcomes following a decision at time t_1

	States of nature	
Actions	S-1 Probability=q	S-2 Probability=1-q
A-1	$q \cdot s$	$(1-q)\cdot(1-s)$
A-2	$q \cdot (1-s)$	$(1-q)\cdot s$

On the basis of the entries in Table 2 and 3 we find that the expected value of a decision at time t_1 is:

$$EV(t_1) = q \cdot s(B-C)-(1-q)\cdot(1-s)\cdot C .$$

The present value of this is:

(4) $$EV(t_1)\cdot\delta = (q \cdot s(B-C)-(1-q)\cdot(1-s)\cdot C)\cdot\delta ,$$

where δ is the present value factor, $\delta = e^{-r \cdot t_1}$, with representing the rate of discount. Obviously, if $r>0$, $\delta<1$. Expression (4) is the expected value at t_0 of retaining the option to decide until t_1. This value is sacrificed if action A-1 is selected at time t_0.

The expected present value of selecting A-1 at time t_0 is

(5) $$EV(1,t_0) = q \cdot B - C ,$$

where $EV(1,t_0)$ denotes the expected present value of choosing A-1 at time t_0.So, at time t_0, the expected net gain of choosing A-2, i.e. keeping the option of choosing again at t_1, i.e. delaying irreversible investments, is:

(6) $$\Psi \equiv EV(t_1)\cdot\delta - EV(1,t_0) = (q \cdot s(B-C)-(1-q)\cdot(1-s)\cdot C)\cdot\delta - q\cdot B + C .$$

Expression (6) is in many respects the basic result of this analysis. If gives the rule for selecting actions at time t_0. If Ψ is positive then action A-2, delaying, maximizes expected present value. If it is negative the expected value maximizing decision is to select A-1.

From (6) is obvious that Ψ can be positive even if $EV(1,t_0)>0$. For that to happen, the value of the retaining the option to choose at t_1, i.e. $EV(t_1)$, only needs to be sufficiently high. This establishes a fundamental result regarding a sensible response to the possibility of global warming:

Result 2

Even if the expected present value of the action to counteract global warming by emission reductions is positive (i.e. the requirement in Result 1 holds), it may still be optimal to refrain from doing so.

It is important to realize that Result 2 enlarges the set of rejecting A-1 compared to Result 1. According to Result 2, even if the conditions in Result 1 are satisfied, i.e. the expected value of action 1 now is greater than action 2, i.e. $EV(1,t_0)$-$EV(2,t_0)>0$ (remember we have, in order to simplify the notation, assumed $EV(2,t_0)=0$ above), which is the requirement implied by result 1, it may still not be optimal to select A-1 because of the option value loss.

Two things primarily are responsible for this result. The first is that some of the resources allocated to counteract global warming under A-1 are imperfectly reversible. If they are perfectly reversible (or malleable), then the option to choose again at the 2nd decision node, t_1 will not be lost and there is not option cost of doing A-1. Secondly, it is necessary that there is some uncertainty regarding global warming and its (negative) impacts. If there is none, the can be no mistakes at decision node 1. To see this more formally just set q=1 in (6) which then reduces to:

(6') $\Psi = (B-C)\cdot(s\cdot\delta-1)$,

which is always negative if $B>C$, so delaying can never be sensible.

According to expression (6), delays, i.e. selection A-2 is more attractive the higher the benefit cost ratio, B/C, and the discount rate, r, and vice versa. This is, of course, economically highly intuitive. More interestingly, the two probabilities in the analysis, i.e. q and s, operate in opposite directions. The higher the probability of global warming, i.e. q is, the less attractive it is, ceteris paribus, to postpone, i.e. select A-2. On the other hand, the higher the probability if taking the right decision at t_1, i.e. the higher s, the more attractive it is , ceteris paribus, to select A-2. In this context, it is worth remembering that due to new information at t_1, $s\geq q$ and the two probabilities are otherwise independent.

Prompted by the last observation, let us examine the pairs of probabilities (q,s) that make I optimal to postpone countervailing actions, i.e. select A-2 at time t_0. The basic condition is that Ψ in expression (6) is positive. Imposing this on (6) and rearranging yields the condition.

(7) $$q < \frac{[1-\delta\cdot(1-s)]\cdot C}{[1-\delta\cdot(1-s)]\cdot C + (1-s\cdot\delta)\cdot(B-C)}.$$

Note, however that not all (q,s) which satisfy this condition are equally relevant. First, of course, both q and s must be in the interval [0,1]. Secondly, to make the decision problem interesting, the expected present value of choosing A-1 at time t_0 must be positive, i.e. $EV(1,t_0)>0$. If that is not the case there can never be any question of choosing A-1 at time t_0, or, in fact, any other time. Thus, according to (5) $EV(1,t_0)>0$ implies the constraint:

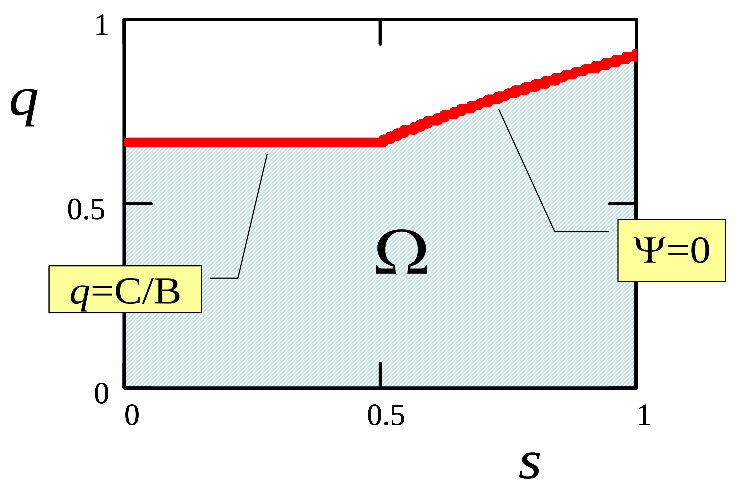
$$(5') \quad q > \frac{C}{B}.$$

The (q,s)-combinations such that it is optimal to select A-2 at time t_0 are thus defined by the set:

$$\Omega = \left[q,s \middle| \; 0 \le q,s \le 1,\; q > \frac{C}{B},\; q < \frac{[1-\delta\cdot(1-s)]\cdot C}{[1-\delta\cdot(1-s)]\cdot C + (1-s\cdot\delta)\cdot(B-C)} \right].$$

An example of this set is drawn as the shaded area in Figure 2. The unshaded area in the figure depicts (q,s)-combinations for which it would be optimal to select A-1 at time t_0. The figure is drawn on the basis that B=3, C=2, r=0.05 and t_1=5. Note that according to these specifications, the benefits of counteracting global warming (if it occurs) are 50% higher than the costs. This is far in excess of what various economic estimates have indicated (see e.g. Nordhaus 1994, Frankhauser et al. 1997, Mendelsohn et al. 2000, Tol 2002, Kemfert 2002 and Kavuncu and Knabb 2005). Less difference between the expected costs and benefits will obviously increase the set Ω.

Figure 2
Ω=(q,s)-combinations for which it is sensible to select A-2 at t_0



CONCLUSION

There is great uncertainty regarding global warming and, even more so, the effects of such warming on the economic wellbeing of the human race. This uncertainty is much greater than many environmentalists suggest and media discourse on the subject indicates.

Even if was taken for granted that global warming is occurring and it is significantly caused by human emission of GHGs, it does not follow that it is sensible to reduce these emissions. The reason is that it is by no means clear the benefits of such an undertaking exceed the costs. Most large scale economic measurements of this that have been conducted (from one of the first Nordhaus 1994 to once of the most recent Kavuncu and Knabb 2005) actually indicate that this may not be so.

Then we have the uncertainty. Even if we assume (contrary to available measurements) that the net present benefits of substantial reductions in the emission of GHGs are strongly positive it may not be optimal to embark on such reductions. The expected value of such a reduction may not be positive. For it to be positive, there needs to be high confidence of (i) global warming, (ii) damaging effects of global warming and (iii) that the reductions in emissions will have the desired impact. On the basis of existing knowledge, this confidence does not appear to be justified.

Then we have the option value of postponing imperfectly irreversible decisions. Even if the expected value of reducing GHG emissions were confidently positive. It might still not be a good idea to adopt that policy. The reason is that there is a chance that this policy might be a mistake, e.g. because global warming was not occurring, its effects were not as damaging as expected or because of some other erroneous assumption. Actually embarking on a GHG emission reduction policy implies the loss of the option to wait and see. This option has a value because the process of GHG reduction inevitably involves irreversibilities of various kinds. So the cost of this sacrificing this option has to be subtracted from the expected value of the GHG reduction policy. As this paper shows that either the expected net benefits of a GHG reduction policy must be very high (high probability of a correct choice combined with the benefits greatly exceeding the costs) or the irreversibility associated with the policy very small (the option value of waiting low) for it to be sensible to embark on this policy.

Needless to say, exactly the same considerations apply to the appropriate policy responses to the threat global warming may pose to fish stocks and fisheries. The thing, however, is that global warming policies are global in nature and thus, for most countries, the economic value of fisheries will hardly be a major factor in formulating these policies.

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