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Complexity, Climate Change and the Precautionary Principle

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Abstract

The precautionary principle has been proposed as a basis making decisions about environmental health under conditions of uncertainty, but remains controversial. This paper shows how the precautionary principle may be interpreted as a guide to decisionmaking in complex systems characterised by unfavorable surprises. The application of the precautionary principle to the problem of climate change is discussed.

Introduction

There is widespread consensus, summarised in the reports of the Intergovernmental Panel on Climate Change (IPCC) (2007a,b,c), that in the absence of mitigation policies, average global temperatures will rise substantially over the next century, with 'business as usual projections' of temperature increases ranging from 2 to 5 degrees Celsius. This increase in temperature will be associated with complex effects on other aspects of climate, such as rainfall patterns and the frequency and intensity of storms, and with consequent effects on natural ecosystems and human activity.

As this very brief summary indicates, the problem of climate change is complex and subject to considerable uncertainty. Policy responses to such complex problems have proved difficult to formulate. Even greater difficulty has been found in securing agreement on which of many possible policy responses to pursue.

One response to these difficulties, particularly in relation to threats to environmental health has been the precautionary principle. Many variants of this principle have been put forward and debated. One of the most commonly cited is derived from from the Wingspread Conference (1998):

When an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause and effect relationships are not fully established scientifically.

Although a range of different interpretations of this statement are possible, most reasonable interpretations would imply support for action to mitigate climate change by reducing or offsetting emissions of greenhouse gases. Hence, acceptance of the precautionary principle as a guide to responses to complex and

uncertain environmental health problems would provide a clear basis for action. However, many critics have argued that the precautionary principle is an unsatisfactory basis for decisionmaking either because it may be applied to prevent any action (in strong versions) or because it lacks any substantive content beyond standard rules of decision analysis (in weak versions).

The purpose of this paper is to analyse the precautionary principle and show how it is applicable to complex and uncertain problems such as climate change. The paper is organised as follows. Section 1 presents background material on the problem of climate change. Section 2 considers objective and subjective views of the global climate change problem as a complex system. Section 3 shows how the precautionary principle may be interpreted as a guide to decisionmaking in complex systems characterised by unfavorable surprises. Section 4 discusses the application of the precautionary principle to the problem of climate change. Finally, some concluding comments are offered.

1. Background

Before considering the role of complexity, it is useful to summarise key aspects of climate change, as described by the IPCC(2007a,b,c), on which this section is based. Some aspects of the problem are well understood, and others much less so.

The physical reasoning underlying the greenhouse effect is scientifically uncontroversial and dates back to the 19th century. Greenhouse gases such as carbon dioxide and water vapour reduce the extent to which heat energy in the atmosphere, derived from solar radiation, is radiated back out into space. Increases in concentrations of carbon dioxide (CO₂) may be expected to raise the equilibrium temperature of the earth's atmosphere. Climate models indicate that this effect will be amplified by positive feedbacks, most notably an increase in atmospheric concentrations of water vapour.

The growth of atmospheric concentrations of the main greenhouse gas, carbon dioxide has been tracked at Mauna Loa, Hawaii since 1957. CO₂ has increased from about 313 ppm (parts per million) in 1960 to about 375 ppm in 2005. This increase is entirely accounted for by human activity, most importantly the burning of fossil fuels and the clearing of forests. Anthropogenic CO₂ emissions have been partially offset by natural sinks, such as absorption by the oceans. In addition to CO₂, human activity has also generated increased atmospheric concentrations of other greenhouse gases, including methane and chlorofluorocarbons (CFCs).

Global temperatures have risen by about 0.75 degrees C relative to the period 1860-1900, with about 0.5 degrees of this increase occurring since 1970. Temperature changes reflect a combination of natural variation and the effects of anthropogenic global warming. The IPCC states that 'Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations', where 'very likely' is explained as a probability between 90 and 95 per cent.

IPCC (2007a,b) presents a range of model-based forecasts of future climate change. The key variables are the projected time path of emissions and the sensitivity of the climate system to 'forcing', conventionally measured as the equilibrium response of global mean temperatures to a doubling of CO₂ equivalent concentrations.

Median values for the projected temperature increase by 2100 range from 2.5 degrees to 4 degrees C depending on the choice of model and scenario. Each projection includes a probability distribution giving a range of uncertainty. For typical projections the standard deviation of the projected temperature change is around 1 degree C.

Ideologically-motivated 'skepticism'

The problems of climate change mitigation and adaptation have been exacerbated by the fact that many of the proposed mitigation policies are politically controversial. Opponents of those policies have responded by rejecting the scientific evidence and by attacking scientific organisations and individual scientists. Calling themselves 'skeptics', critics have attacked every aspect of the mainstream analysis from data on CO₂ concentrations, to the historical temperature record, to projections of future climate change and its impacts. With a handful of exceptions, those making these attacks are not active climate scientists. Among that handful, nearly all have financial ties to the fossil fuel industries, ideological associations with anti-environmental thinktanks or both.

As regards the concerns of this paper, the fact that a large group of participants in public debate is actively seeking to increase, rather than reduce, uncertainty about all aspects of the problem raises some important difficulties. However, as will be shown below, uncertainty about the problem does not necessarily strengthen the case for inaction.

2. A complex system

It is apparent that the combination of human activities and natural processes that produces climate change is a highly complicated process, and that a wide variety of interactions take place between socioeconomic, biological and atmospheric systems to produce outcomes that are subject to a great deal of uncertainty. Hence, it is natural to speak of a complex system.

However, without a clear understanding of what is implied, the use of 'complex systems' terminology may conceal as much as it reveals. In the present case, it is useful to distinguish between objective properties of the system, and subjective aspects of our understanding of that system.

The objective view

From an objective viewpoint, the set of interactions involved in climate change has many of the characteristics commonly associated with complex systems. First, important aspects of the system are highly nonlinear.

Because of nonlinearity of the atmospheric system, daily weather patterns are impossible to predict more than about a week ahead, even with powerful computers and extensive data. In highly nonlinear systems, slight variations in initial conditions lead to much larger deviations in equilibrium paths over time. The 'butterfly effect' in which a butterfly flapping its wings in one location might make the difference between the occurrence or non-occurrence of a cyclone in another location at a later date is a popular metaphor for the chaotic behaviour of such nonlinear systems.

In some cases, nonlinearities in the system may act to enhance stability. For example, the forcing effect of CO₂ is not linear but is proportional to the logarithm of CO₂ concentrations, so that the direct marginal impact of additional units of CO₂ declines as the existing concentration increases.

On the other hand, other nonlinear effects generate instability, leading to concerns about a possible runaway greenhouse effect, as has taken place on Venus. Some of these nonlinearities arise from interactions within the climate system, such as changes in the dynamics of cloud formation and in the development of tropical cyclones.

Complex nonlinear effects may arise from interactions between climatic and biological systems. For examples, increased temperature may lead to more frequent and more severe bushfires which in turn produce massive emissions of CO₂.

Nonlinear systems often display threshold effects, in which the system jumps from one mode of behaviour to another when some input exceeds a critical value. For example, CO₂ emitted from human activity may be absorbed by natural

sinks. When the capacity of these sinks is exhausted, the rate of growth of atmospheric concentrations of CO₂ may increase sharply.

A threshold effect that has received significant attention is the possible sudden shutdown of the thermohaline circulation that drives ocean currents. Such an event could lead to cooling in the North Atlantic, which is currently warmed by the Gulf Stream.

An important characteristic of complex systems is that of emergent effects. Such effects arise when behaviour at some scale of aggregation, such as a national economy or a global climate system cannot be derived by modelling behaviour at a more disaggregated scale, such as that of individual industries or components of the climate system. Rather, the system as a whole has properties that cannot be deduced from the behaviour of its components.

Climate change is a phenomenon that takes place at many scales, from the atmosphere as a whole to local micro-climates and the ecosystems and socioeconomic systems they support. A wide range of emergent effects must be taken into account.

The subjective view

For policy purposes, the objective characteristics of a system are only indirectly relevant. What matters is the subjective representation of the system available to decisionmakers. It is this subjective representation that forms the basis of policy choices.

Objective complexity generally implies subjective complexity, but this is not always the case. More importantly, limited understanding of the properties of a system lead to subjective complexity even in cases where the objective behaviour of the system is linear and deterministic.

For example, the behaviour of the solar system may be explained and predicted (up to a very good approximation) using Newtonian physics. However, when

understanding of the system was based on a heliocentric model of the universe with circular motion, observed behaviour could only be explained by a complex system of cycles and epicycles.

In the case of climate change, the objective complexity of the system is exacerbated by our limited understanding of crucial natural, economic and social components of that system. This uncertainty arises at multiple levels.

First, within any given model, parameters are uncertain. In typical global climate models, for example, estimates of sensitivity to a doubling of CO₂ concentrations may vary in a range of 2 degrees or more depending on assumptions about feedbacks and the values of other parameters (IPCC 2007a).

Second, there are multiple models which yield different projections, even with the same settings for standard inputs and parameter values. Decisionmakers must consider whether to choose a particular model as their preferred tool for analysis or to integrate results from multiple models.

Third, and more fundamentally, there may be surprises not yet taken into account in models, which may generate new and unexpected feedbacks. For example, climate models at present do not take into account the climatic impacts of more severe forest fires.

Even if the underlying behaviour of a system is linear and deterministic, the fact that human beings are boundedly rational creatures means that our understanding is always limited. In attempting to understand any sufficiently complicated problem, whether or not the associated system is objectively complex in the sense described above, our analysis will inevitably omit important details.

3. The Precautionary Principle

Many versions of the precautionary principle have been put forward. As noted above, the definition put forward by the Wingspread Conference (1998) provides a useful basis for discussion. Critics such as Sunstein (2005) have pointed out

that, taken literally, the precautionary principle is self-contradictory. All activity of any significance raises threats of harm to human health or the environment in one way or another. In particular, unnecessary precautions waste resources that could be used to promote health or the environment.

Moreover, the phrasing of the principle with reference to 'an activity' embodies the implicit assumption that there exists a *status quo* option in which no activity is undertaken. This assumption may be appropriate for some applications. In general, however, no such option exists, and it is necessary to choose between alternatives, all of which involve change and may potentially create risks. As the saying has it, 'not to decide is to decide'.

However, it is possible to rationalise the precautionary principle as a guide to management of complex systems. Complete understanding of such systems is unattainable. However, it is often possible to distinguish between decisions where the consequences are understood fairly clearly, at least in a probabilistic sense, and those that are likely to generate unanticipated possibilities or surprises.

In some systems, surprises may be favourable. In others, however, such as those typically involved in environmental health, most surprises are unfavorable. We may refer to a system involving a large number of unanticipated possibilities, most of which are likely to be unfavorable, as a *domain of unfavorable surprises*.

It is in the nature of complex systems that the statements of propensity or likelihood used in the characterisation of a domain of unfavorable surprises cannot usefully be expressed in probabilistic terms, and are therefore not amenable to a risk analysis using the tools of classical or Bayesian decision theory. However, it is possible to derive notions of reasonable belief that are appropriate to problems of this kind (Halpern 2003, Grant and Quiggin 2006). Using these approaches, it is possible to integrate concepts such as 'burden of proof' into a decision-theoretic analysis.

Hence, we proposed the following reformulation of the precautionary principle:

Where a proposed course of action in the management of a complex system may lead to unfavorable surprises, such as threats to environmental health, the burden of proof should be on the proponents of the course of action to demonstrate reasonable grounds for belief that it will not be harmful.

This reformulation overcomes objections like those of Sunstein (2005) by characterising activities and domains where the precautionary principle is, and is not, applicable. Moreover, it avoids the implicit assumption that there is a *status quo* option.

Heuristics

The analysis of the precautionary principle presented here supports a range of heuristics regarding complex choices that have proved useful in a variety of contexts.

First, it is desirable before making a decision to identify areas of high uncertainty and reduce such uncertainty as much as possible. This is a generally accepted principle of risk analysis.

Second, it is important to avoid excessive reliance on point estimates of crucial parameters. Although some sensitivity analysis is commonly undertaken in benefit–cost analysis, evidence suggests that allowance for unexpected variations is commonly inadequate, particularly in relation to large-scale ‘megaprojects’ (Flyvbjerg, Bruzelius and Rothengatter 2003).

Third, it is important to place an appropriate value on flexibility and on the maintenance of a range of options. The relationship between option value and the precautionary principle has been discussed by Gollier, Jullien and Treich (2000).

Finally, the precautionary principle gives some support to the use of rules of thumb with a track record of reliability, even where a formal risk analysis suggests that these rules of thumb may be overly cautious. The case-based decision theory of Gilboa and Schmeidler (1995) provides a useful approach to the application of such rules.

4. Application to climate change

The formulation of the precautionary principle developed here applies naturally to climate change. Although there are a wide range of possible options, we may simplify here by considering two options.

The first, 'business as usual' suggests that existing economic and social arrangements should not be changed in response to the risk of climate change. If policies that reduce CO₂ emissions, such as improvements in the fuel-efficiency of motor vehicles, are to be adopted, they should be justified on other grounds.

The second, 'stabilisation' involves stabilising atmospheric concentrations of CO₂ equivalents at a level consistent with an eventual increase in global temperatures of no more than 2 degrees. Most current assessments suggest that the required stabilisation target is a concentration of between 500 and 550 ppm. The implied requirement is for a reduction in CO₂ emissions of 60 per cent relative to business as usual.

In many contexts, 'business as usual' is taken to be the default option. In the case of climate change, however, continuing business as usual involves a cumulative increase in atmospheric CO₂ concentrations to levels well beyond any in the range of human experience. The consequences of such an increase are inherently unpredictable. There are too many interactions and feedbacks to take them all into account, and some of them will undoubtedly involve unpleasant surprises. Perhaps the biggest single area of unpredictability relates to natural ecosystems. Given a substantial change in global temperatures, many species will undoubtedly become extinct. With an increase of only 1.5 degrees, as many

as one-third of all species would be at risk of extinction (IPCC 2007c). With more rapid increases, a mass extinction event is increasingly likely. The full consequences of such an extinction event are beyond our capacity to predict, or even to consider.

By contrast, the consequences of a stabilisation policy are understood fairly well, by economists at least. The only feasible method of reducing CO₂ emissions by the amount required is to impose a price on such emissions, either directly through a carbon tax or indirectly through a system of tradeable emissions permits. Standard methods of economic analysis may be used to estimate the likely impacts of such a price change.

The crucial variables in assessing the impact of a price change for any good are the elasticity (price-responsiveness) of demand and the share of the good in economic activity as a whole. Popular discussion tends to overestimate the economic importance of carbon-based fuels and underestimate the elasticity of demand. In fact, carbon-based fuels account for around 5 per cent of economic output. In the short run, demand for energy is inelastic. However, as the experience of the 1970s showed, a sustained increase in energy prices produces large reductions in demand over periods of a decade or more (Quiggin 2006).

A number of independent estimates of the cost of a stabilization policy have been undertaken by economists with a range of views on climate policy. All such estimates imply a small reduction in the value of economic output, with most estimates lying in the range from 1 and 3 per cent. Although energy-intensive activities will contract significantly, this will be offset by expansion of other parts of the economy. Application of the precautionary principle therefore suggests that stabilisation is the appropriate policy response.

A detailed analysis of the policy responses required for the implementation of a cost-effective and flexible stabilisation policy is beyond the scope of this paper. However, there are strong arguments to suggest that Australia should abandon

its opposition to the Kyoto protocol, and move rapidly towards the establishment of a system of emissions trading, beginning with major sources such as electricity and automotive emissions and moving towards a more comprehensive scheme over time (Gans and Quiggin 2007). We would then be in a position to participate in negotiations aimed at ensuring the active participation of developing countries such as India and China in a post-Kyoto agreement to begin in 2012.

Concluding comments

The precautionary principle is an important element of public policy in response to threats to environmental health, such as climate change. However, the principle remains controversial, and its implications in particular cases are not always clear.

In this paper, the precautionary principle has been reformulated with specific reference to complex systems. In such complex systems, the complete examination of all possible outcomes presupposed in probabilistic approaches to risk analysis is not possible, and unforeseen outcomes (surprises) may occur. If a course of action lead to domains where unfavorable surprises are likely, the burden of proof should be on the proponents of the course of action to demonstrate reasonable grounds for belief that it will not be harmful.

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