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# Uncertainty and climate change policy

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*Abstract*

The paper consists of a summary of the main sources of uncertainty about climate change, and a discussion of the major implications for economic analysis and the formulation of climate policy. Uncertainty typically implies that the optimal policy is more risk-averse than otherwise, and therefore enhances the case for action to mitigate climate change.

# Uncertainty and climate change policy

The problem of climate change has been described as ‘a unique challenge for economics: it is the greatest and widest-ranging market failure ever seen’ (Stern 2007, p. i). Among the factors that make climate change a difficult problem, the most important is uncertainty about the future course of climate change, and the effect of policies aimed at mitigating climate change. There are a great many sources of uncertainty inherent in the modelling and prediction of a complex process like climate change. In addition, political opponents of policies to mitigate climate change have promoted spurious uncertainty to provide a justification for their position.

Although there is a large literature on the economic analysis of choice under uncertainty, many crucial issues are poorly understood by policymakers and the general public. In particular, uncertainty about climate change under ‘business as usual’ policies is commonly seen as a reason for inaction. However, uncertainty typically implies that the optimal policy is more risk-averse than otherwise, and therefore enhances the case for action to mitigate climate change.

The paper consists of a summary of the main sources of uncertainty about climate change, and a discussion of the major implications for economic analysis and the formulation of climate policy.

## 1. Sources of uncertainty

Projections of future climate change are derived from large scale dynamic models of the global climate system. Although economists have no special expertise in assessing the details of these models, the economics profession has long experience with the general properties of large scale dynamic models, and with the various sources of uncertainty surrounding these models. In this section, a variety of sources of uncertainty are considered.

*Model uncertainty*

A large number of global climate models have been constructed by different groups of researchers. All such models share the same general form, consisting of a large system of differential equations designed to simulate long-term changes in atmospheric and ocean systems. These equations are converted to discrete form for a grid modelling the entire global system at a resolution determined by limits on data and computational capacity. A summary of the modelling literature is provided by the Intergovernmental Panel on Climate Change (2007a).

There are a large number of choices that must be made in constructing such a model. These include choices of functional form for equations, specification of variables, and the details of the process of discretisation and estimation. Inevitably, different choices lead to different results. On the other hand, the requirement for consistency with the observed data and with fundamental physical principles constrains the extent to which model predictions can differ. (Thorpe 2005).

The central point may be illustrated with a comparison to macroeconomic models. These also vary widely, and their predictions will differ. Nevertheless, despite the existence of a range of uncertainty, all macroeconomic models will predict a substantial increase in inflation in response to a doubling of the money supply, just as all climate models predict a substantial increase in global temperatures in response to a doubling of atmospheric $CO_2$ concentrations.

*Parameter uncertainty*

The parameters of any model are estimated with reference to the available data. Given a finite data set, parameters are inevitably estimated with error, and this error creates uncertainty with respect to predictions.

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The crucial parameter in a global climate model is climate sensitivity, that is, the sensitivity of equilibrium global temperature to a given change in 'forcing'. Forcing is the heating effect derived from changes in the concentration of greenhouse gases or other sources. Sensitivity is conventionally measured as the equilibrium response of average global temperature, to a doubling of the total forcings derived from greenhouse gases, measured in $CO_2$ equivalent parts per million. This is a useful basis for discussion since continuation of 'business as usual' policies is likely to generate a doubling of $CO_2$-equivalent concentrations from the pre-industrial level by around the middle of the present century.

It is important to interpret climate sensitivity carefully. On the one hand, it is an equilibrium measure, so the estimated change in temperature will not take place immediately. On the other hand, under business as usual, there is no reason to expect that $CO_2$ concentrations will stabilise at twice the pre-industrial level.

A variety of estimates of climate sensitivity have been presented, some as point estimates and some with a range of uncertainty. Two issues are particularly relevant. First, for much of the historical period on which estimates have been based, both concentrations of $CO_2$ and concentrations of other pollutants generated by industrial production (collectively referred to as 'aerosols') were growing. Hence these variables display collinearity over most of the data period. Since around 1960 however, concentrations of aerosols have declined as a result of legislation restricting air pollution, while concentrations of $CO_2$ and other greenhouse gases have continued to increase.

Most aerosols operate to reduce warming, and thus have an opposite effect to that of emissions of $CO_2$. The combination of collinearity and opposite effects mean that the larger is the estimated effect of aerosols, the larger is the estimate of climate sensitivity, working in the opposite direction to produce a given change in temperature. It follows that a wide range of pairs of parameter values can fit the observed movement in global mean temperature, particularly over the period when aerosol and $CO_2$ concentrations were highly collinear. This source of parameter uncertainty can be reduced by the use of more recent data and by comparing trends in the Northern Hemisphere (where industrial pollution has produced high levels of aerosols) with those in the Southern Hemisphere (where aerosol levels were lower) (Harvey 2000).

Another important issue is the choice between classical approaches to parameter uncertainty, which have dominated the literature, and Bayesian approaches that allow the incorporation of relevant information from a variety of sources. Bayesian methods generally imply less uncertainty about parameter values than classical methods. Stainforth et al. (2005), using a classical approach suggest that sensitivity may be as high as 11 degrees Celsius, whereas Annan and Hargreaves (2006) argue that the correct value almost certainly lies between 1.5 and 4.5 degrees Celsius.

*Uncertainty about emissions*

Perhaps the most important single source of uncertainty, in forecasting likely climatic conditions in the future, relates to future growth of, or reductions in, emissions in $CO_2$ and other greenhouse gases. Some 'business as usual' projections imply continuing growth in emissions, broadly in line with growth in income (Intergovernmental Panel on Climate Change 2007c). By contrast, policy proposals currently under discussion call for reductions in emissions of 50 to 90 per cent, relative to current levels, by 2050 (Stern 2007; Garnaut Climate Change Review 2008). The relationship between climate change and uncertainty about emissions is complicated by the fact that the policy choices that will help to determine future growth in emissions are themselves a response to projections of future climate change.

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For some purposes, such as planning for adaptation to climate change, the primary concern is to predict future climate change as accurately as possible, taking account of all relevant factors. From this perspective the adoption or rejection of policies to reduce emissions is just one more factor to take into account.

By contrast, in discussing climate change mitigation, we are comparing the outcomes of alternative courses of action.

A simple identity helps to illustrate the uncertainties involved in projecting emissions of $CO_2$ from energy generation (the most important single source of greenhouse gases.

Emissions = Population*Output/Population*Energy/Output* Emissions per unit Energy (1)

Hence the rate of change of emissions is equal to the sum of the rates of change of the variables on the right-hand side.

Most ‘business as usual’ projections assume that: global population will stabilise at around 9 billion after 2050; output per person will grow at a rate of around 2 per cent per year; and energy intensity of output will decline as incomes rise, but that energy use per person will continue to increase. Projections of the emissions intensity of energy use in the absence of policy intervention vary widely, with some projections suggesting continued reliance on fossil fuels, most notably coal, while others suggest that exogenous technological innovations will lead to the displacement of coal by alternative energy sources.

*Uncertainty about other forcings*

Although the growth in emissions of greenhouse gases is the main cause of the increase in global temperatures, many other forcings affect climate. None of these forcings displays a consistent long term trend, and therefore none can explain the long term growth in mean global temperatures, but uncertainty about these forcings contributes to uncertainty about future warming. Important examples include variation in the intensity of solar output and changes in the concentration of various aerosols including black soot.

*Feedbacks, sinks and lags*

The direct forcing effects of increased atmospheric concentrations of carbon dioxide can be determined fairly accurately from simple physical models. However, the final impact of any given level of $CO_2$ emissions, and the speed with which the global climate system reaches a new equilibrium depend on a complex set of feedbacks, sinks and lags (Intergovernmental Panel on Climate Change 2007a).

Climate models take account of feedbacks and lags operating within the atmosphere and, to some extent, the capacity of oceans and other global systems to absorb $CO_2$. But there are many other potential feedbacks that are poorly understood. For example, higher temperatures may lead to more, and more severe, bushfires, with a resulting increase in $CO_2$ emissions.

*Uncertainty about costs and benefits*

Even assuming that future changes in temperature could be projected with certainty, there would be considerable uncertainty about the costs and benefits. The largest economic impacts of climate change are likely to be those affecting agriculture. Surveying the literature on this topic, Quiggin (2008) notes:

> Analysis of the impact of climate change on agriculture raises yet more complexities. The effects of changes in temperature and climate will vary across different regions, so that climate change will be beneficial in some areas and harmful in others. It is necessary to take account of adaptation to climate change, and therefore to take account of both the pace of change and the impact of uncertainty on human behaviour. Finally, to reach an economic evaluation of the impact of climate change, it is necessary to aggregate changes taking place in different parts of the world, at different times ranging from the present to at least the middle of this

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> century, and affecting different people, some of them not yet born.

Looking specifically at Australian irrigation, Adamson, Mallawaarachchi and Quiggin (2007) find that the severity of climate change depends not only on projected changes in mean precipitation (snowfall and rainfall), but on whether reductions in precipitation take the form of a generally drier climate or of an increase in the frequency of severe droughts, such as that being experienced at present.

*Fabricated uncertainty*

Many of the sources of uncertainty described above are common to all forecasts and projections of all kinds. However, the typical aim of policy analysis is to reduce uncertainty as far as possible, and thereby to permit the formulation of policy on the basis of the best available evidence.

Unfortunately, many participants in the debate about climate change are not concerned to reduce uncertainty, but rather to increase it, with the objective of preventing or delaying policy responses to which they object, either on ideological grounds or because they are funded by firms such as ExxonMobil, which are likely to suffer financial losses as a result of action to reduce $CO_2$ emissions (Royal Society 2006).

One aspect of this process was noted by Burkeman (2003), citing a 2002 memo from Republican strategist Frank Luntz to US President George Bush:

> "The scientific debate is closing [against us] but not yet closed. There is still a window of opportunity to challenge the science," Mr Luntz writes in the memo, obtained by the Environmental Working Group, a Washington-based campaigning organisation.
>
> "Voters believe that there is no consensus about global warming within the scientific community. Should the public come to believe that the scientific issues are settled, their views about global warming will change accordingly.

> "Therefore, you need to continue to make the lack of scientific certainty a primary issue in the debate."

The scientific literature on climate change is virtually unanimous regarding the validity of the mainstream model (Intergovernmental Panel on Climate Change 2007a, Oreskes 2004), and those seeking to manufacture uncertainty (commonly self-described as ‘skeptics’) have not undertaken significant peer reviewed research to justify an opposing conclusion. Rather they have attacked climate scientists and science itself through a range of think tanks, ‘Astroturf’ organisations and articles in the mass media, on blogs and through other media.

In the Australian debate, the attempt to fabricate uncertainty with respect to the science of global warming has been documented by Hamilton (2007), Pearse (2007) and others. Among organizations promoting spurious uncertainty about climate science, the most notable have been the Institute of Public Affairs (a politically conservative, industry funded think tank active on a wide range of issues) and the Lavoisier Group (one of a number of closely associated single-issue groups originally established using the resources of the Western Mining Corporation).

**2. Implications for climate policy**

Considering all possible sources of uncertainty, a reasonable range of projections for the change in global temperature between the present and 2100 would range from zero to 8 degrees Celsius. A reasonable range for the outcome of aggressive mitigation polices would run from below zero to around 4 degrees Celsius.

To obtain the low end of these ranges, it is necessary to assume that:

(i) climate sensitivity is at the low end of plausible estimates (say 1.5 degrees Celsius) ;

(ii) adjustment lags are long;

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(iii) a significant part of the increase in global temperatures observed in recent decades is due to non-greenhouse forcings which will decline in the future; and

(iv) exogenous technological changes will limit, and eventually reverse, growth in the consumption of fossil fuels.

For estimates at the high end, it is necessary to assume:

(i) climate sensitivity is at the high end of the range of plausible estimates (say 4.5 degrees Celsius);

(ii) adjustment lags are relatively short, and likely to become shorter as sinks are exhausted;

(iii) positive feedbacks will play an important role; and

(iv) in the absence of aggressive mitigation, there will be no early shift away from fossil fuels.

The plausible range of damages associated with a 'business as usual' policy range from zero (or perhaps small net benefits) to catastrophic damage including the extinction of most animal and plant species and threats to the viability of our current civilisation. Although the probability of the extreme outcomes is relatively small (perhaps 5 per cent based on current understanding) they cannot be ignored in formulating policy.

With aggressive mitigation, the range of net damages ranges from 1–2 per cent of global income (a low range estimate of the economic cost of mitigation) to perhaps 10 per cent of income in the case when mitigation is expensive and only partially successful.

*Economics of uncertainty*

The economic literature on choice under uncertainty, dating back to early long; contributions such as those of Arrow (1951) and Pratt (1963), is huge. However, a few basic findings of this literature are sufficient to resolve many of the critical issues in the debate. Most importantly, uncertainty about the effects of climate change implies a requirement for more mitigation, not less. There are several reasons for this.

First, expected damage, measured in either physical or monetary terms, is a convex function of the rate of change of global temperature. An increase in global mean temperatures of 4 degrees Celsius over the next century would cause far more than twice the damage associated with an increase of 2 degrees Celsius, and an increase of 8 degrees Celsius would be utterly catastrophic. So, the expected damage associated with an uncertain future increase in temperature is more than that associated with a mean or median projection of temperature change.

Second, risk aversion implies that the value of a marginal increase in income is greater, the lower the level of income. Since mitigation will yield the greatest benefit in cases where the economic loss associated with climate change is largest, and therefore when income is lowest, the certainty equivalent of the benefits of mitigation exceeds the expected value.

Finally, as noted above, the possibility of catastrophic damage from climate change cannot be ignored. This implies that the only sustainable policies are those that minimise the risk of catastrophic damage. One way of addressing such risks is through the precautionary principle, which implies that we should avoid courses of action with poorly-understood possibilities of highly adverse outcomes (Quiggin 2006, Weitzman 2007).

These points is illustrated by the economic analysis undertaken in the Stern Review (Stern 2007), which reported estimates of expected damages ranging from 5 per cent to 20 per cent of global income under a policy of 'business as usual'. The high estimate is dominated by relatively low probability events involving large (though not catastrophic) losses. Although Stern's estimates do
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not include a formal evaluation of the expected costs of catastrophic losses, the possibility of catastrophe is cited as a further reason for immediate action.

Because the damage associated with climate change is potentially catastrophic, it is important to consider the entire probability distribution, rather than a limited number of parameters such as mean and variance. Policy options that provide protection against low probability events in the right-hand (high damage) tail of the distribution yield substantial expected benefits.

This is an important result to bear in mind when reading the work of those who profess to be sceptical of the findings of mainstream climate science, whether they are motivated by honest doubt or by ideological or financial motives. To the extent that mainstream scientists may be in error, they are equally likely to err in either direction. And the dangers of underestimating the pace of climate change are greater by far than the dangers of overestimation. So, the more uncertain we are about the outcomes, the more certain we should be about the need to take action that reduces the rate of climate change.

Because uncertainty will be resolved over time, it is important to maintain flexibility. Flexibility to adjust policy in the light of new information allows us to capture the option value associated with deferred choice. The literature on real options (Trigeorgis 1993) provides methods by which option value can be traded off against the cost reductions that may be associated with early commitment to a given path of emissions.

There is unlikely to be much difficulty in maintaining flexibility to relax mitigation policy if the problem of climate change turns out to be less serious than the current median estimate. Governments can cut taxes on carbon, give away additional emissions permits and relax regulatory constraints, all of which will generally be popular moves. It will be rather more difficult to maintain the flexibility to move to more aggressive mitigation policies than are contemplated in initial agreements.

The most important task in the short run is to create institutions, such as emissions trading schemes that can deliver substantial reductions in emissions. At this stage, long term targets, such as the reduction in emissions to be achieved by 2050, should be regarded as indicators of willingness to act rather than firm commitments.

**Concluding comments**

Uncertainty about the rate of climate change and its consequences has important implications for public policy. The main implication as discussed above, is that the optimal mitigation effort is greater than it would be if the median projection of climate change were known, with certainty, to be correct.

As uncertainty is resolved over time, policy should be adjusted in the light of new information. Perhaps this new information will show that the problem of climate change is less severe than current evidence suggests. More likely, it will bring to light new aspects of the problem that have not yet been considered. Either way, uncertainty about the future does not justify inaction in the present.

**References**

Adamson, D., Mallawaarachchi, T. and Quiggin, J. (2007), 'Climate change and climate uncertainty in the Murray–Darling Basin', paper presented at 51st Annual Conference of the Australian Agricultural and Resource Economics Society, Queenstown, New Zealand, 13–16 February.

Annan, J.D. and Hargreaves, J.C. (2006), 'Can we believe in high climate sensitivity?', unpublished working paper, http://www.citebase.org/abstract?id=oai:arXiv.org:physics/0612094.

Arrow, K. (1951), 'Alternative approaches to the theory of choice in risk-taking situations', *Econometrica*, 19, 404–37.

Burkeman, O. (2003), Memo exposes bush's new green strategy, *The Guardian*, http://www.guardian.co.uk/environment/2003/mar/04/usnews.climatechange

Hamilton, C. (2007) *Scorcher: The Dirty Politics of Climate Change (Black Inc. Agenda),* Black Inc. Agenda, Melbourne.

ments.

Harvey, L.D.D. (2000), ‘Constraining the Aerosol Radiative Forcing and Climate Sensitivity’, *Climatic Change*, 44(4), 413-18.

Intergovernmental Panel on Climate Change (2007), ‘IPCC Fourth Assessment Report: Climate Change 2007’, IPCC, Geneva.

Intergovernmental Panel on Climate Change (2007), ‘Working Group I Report (WGI): Climate Change 2007: Summary for Policymakers’, IPCC, Geneva.

Intergovernmental Panel on Climate Change (2007), ‘Working Group I Report (WGI): Climate Change 2007: The Physical Science Basis’, IPCC, Geneva.

Intergovernmental Panel on Climate Change (2007), ‘Working Group II Report (WGII): Climate Change 2007: Impacts, Adaptation and Vulnerability’, IPCC, Geneva.

Oreskes, N. (2004), ‘Beyond the ivory tower: the scientific consensus on climate change’, *Science*, 306(5702), 1686-1686.

Pearse, G. (2007) *High & Dry: John Howard, Climate Change and the Selling of Australia's Future,* Viking /Penguin, Camberwell, Victoria.

Quiggin, J. (2006), The precautionary principle in environmental policy and the theory of choice under uncertainty, Risk and Sustainable Management Group Working Paper M05_3, 27/4/2005, University of Queensland.

Quiggin, J. (2008), ‘Counting the cost of climate change at an agricultural level’, *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, 2(092), 1–9.

Society, R. (2006), ‘Royal Society and ExxonMobil’, 4 Sep, Policy Statement, Royal Society, http://royalsociety.org/displaypagedoc.asp?id=23780

Pratt, J. (1964), ‘Risk aversion in the small and in the large’, *Econometrica*, 32(1), 122–36.

Stainforth, D.A. et al. (2005), ‘Uncertainty in predictions of the climate response to rising levels of greenhouse gases.’, *Nature*, 433(7024), 403-06.

Stern, N. (2007) *The Economics of Climate Change – the Stern Review,* Cambridge University Press, Cambridge.

Thorpe, Alan J. (2005), ‘Climate Change Prediction: A challenging scientific problem’, Institute of Physics, http://www.iop.org/activity/policy/Publications/file_4147.pdf.

Trigeorgis, L. (1993), ‘Real options and interactions with financial flexibility’, *Financial Management*, 22(3), 202–24.

Weitzman, M. (2007), 'The Stern Review of the Economics of Climate Change', *Journal of Economic Literature* 45(3), 703-24.

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