Unpacking Climate Precaution: Theory and Practice in Decision Making Under Uncertainty

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Introduction

Throughout the climate change debate there have been arguments as to whether uncertainty over future impacts and responses increases or decreases the need for immediate action. Environmental groups argue in favour of precautionary action to guard against unexpected climatic impacts, while most industry groups argue for a wait-and-see approach in order to avoid potentially unnecessary changes in the capital stock.

The striking feature of these positions is not their content, but how seldom they appeal to the existing literature on decision making under uncertainty. The lack of a debate based on systematic consideration of how different factors interact has led to these positions taking on the status of dogma, seemingly unable to be illuminated by empirical research. However, the truth is that many important influences on policy making under uncertainty can be measured, and there is considerable scope to unpack the debate into its different components.

The lack of communication between decision theory experts and the climate policy world is the fault of both sides, but perhaps lies more with those originating the ideas. In general, the descriptions of decision-making methods are too technical for policy makers to understand, and very little effort is made to translate them into familiar everyday concepts such as insurance. Furthermore, by concentrating on particular mathematical models they often fail to capture the full range of concerns and subtleties present in the climate policy problem. This has sometimes led to overly strong policy recommendations which fail to survive close examination of their underlying assumptions. Such failures in analytical presentation discredit the use of systematic approaches in the climate debate, which can only be harmful in the long term.

It is vital that the quality of debate is improved. Unlike the anonymous optimisers of the market, which are assumed to build “rational expectations” of the future to gain a fair approximation of optimisation, in forming climate change policy we cannot quickly learn from trial and error whether our strategies are correct. Many vital decisions will have to be made in a position of long-run uncertainty, where political and economic decision makers will never see the outcome of their actions. This means that the success of policies will not only depend on their logical formulation and the choice of instruments, but also the credibility and longevity of the institutions which are tasked with implementation.

This paper discusses some of these issues in depth and tries to relate existing formal models to practical policy evaluation. The first section gives a brief description of the generalised formal methods used in these areas, to set the context for an examination of how the results and limitations of these methods can be communicated to policy makers in a useful manner.

Beyond Best-Guesses: Theories of Decision Making Under Uncertainty

Since the failure of best-guess forecasting in the 1970s to predict future resource potentials there has been increased interest in how uncertainty should be included inside decision making. The most mature fields are probably risk-assessment (especially in toxicology and nuclear safety); financial analysis (options, derivatives and portfolio management); and macroeconomic modelling (interest rate and currency movement analysis).

The problems with using best-guesses, or mean values, of uncertain parameters to form policy is most elegantly shown by the following expression (adapted from Hall and Stephenson, 1990):

$$\max\ H(X,U,\bar{\varepsilon}) \_ \max\ \mathrm{E}[\mathrm{H}(\mathrm{X},\mathrm{U},\varepsilon)]\ \forall\ \mathrm{X},\mathrm{U}.$$

Where H(..) is a function describing the output of a system of X endogenous or uncontrollable exogenous variables; U is a vector of control variables; ε is a vector of stochastic error distributions surrounding the components of X and U and ε bar the vector of mean error terms. **E** is the expectations operator.

In the case of climate change: H would describe total global welfare, discounted in some way; X describes the natural and economic systems; U the available portfolio of mitigation and adaptation actions; and ε the various uncertainties in the system.

The best-guess approach is represented by the left-hand side of the expression, where values of U are chosen to optimise the system based on the average values of the stochastic errors. The right-hand side of the expression represents a full stochastic optimisation of the system, where the expectation of the system output is maximised over all potential values of ε.

It can be seen that a best-guess approach will not lead to the correct values of U being chosen if H(..) varies in a non-linear manner, because **E**[H(..)] will be influenced disproportionately by non-mean values of ε. If the system was linear over all possible ranges of uncertainty then using the mean values of ε would be correct as it reduces to a certainty equivalent system.

The intuitive difference between the two methods is that in the stochastic optimisation the control vector U is reoptimised for each potential uncertain state of the world. That is, the need for future reactions to uncertain events is taken into account. In the best guess case U is only optimal for the mean values of ε, and no allowance is made for the need to react in the future to different values of the uncertain parameters and variables.

It is unsurprising that the best guess approach gives incorrect answers, because by using the mean values much of the useful information in the probability distributions is discarded (notably estimates of variance and skew). This demonstrates the first simple rule of policy making under uncertainty:

A good policy made under uncertainty cannot be judged by how near it eventually is to the *ex post* optimum as this could be fortuitous. A good policy is one which makes optimal use of all available information.

Though this rule seems obvious, the importance of communicating it to policy makers is paramount. Examination of much of the policy literature shows that many commentators think of uncertainty in point terms - for example, "climate impacts are uncertain" - rather than as a range of outcomes with different probabilities. Therefore, trade-offs are presented as being between certainty - that is immediate abatement costs - and uncertainty - the benefits of mitigation - in a way that poses the binary question - which choice will be right? Rather than the correct question of - which choice is best?

The results of general models show that optimal present policy usually depends on the potential range (variance) and severity (skew) of future impacts, not just their mean, because the cost of responding to what actually happens will be in part determined by past control actions. However, though the link between present and past might seem obvious, it crucially depends on the presence of two factors in the system: learning and irreversibility (a temporal non-linearity).

Learning and non-linearities in climate change policy

Stochastic optimisation only applies in situations where the state of the world will be revealed, or information predictably improves over time, so that at some point the future optimal control reactions can be taken. Some theoretical models of climate change decision making (notably Ulph and Ulph, 1994) have termed this resolution of uncertainty "learning", though this is different to other definitions of learning which apply to unpredictable updating of the probability distributions[1].

The case of non-learning is not as abstract as it may seem. If climate change was immediately halted through vigorous abatement, and the true reaction of the climate to increased levels of GHGs could never be found by research, the world would be locked into a high abatement future with no prospect of escape (Dixit and Pindyck, 1993). However, as unfortunately concentrations will continue to increase in the near future, and the impacts of climate change are already highly apparent, this scenario is unlikely to hold in reality.

Assuming that we will better understand the impacts and extent of climatic change in the future, the value of moving beyond best-guess methods is determined by the existence of irreversible, or dynamic, effects which affect our ability to react to

[1] This type of learning can occur either due to the passage of time or exogenous research (passive learning), or through positive exploration of system characteristics by manipulation of the control vector U (active learning).

revealed future uncertainties. For climate change there are three important types of non-linearities which have been identified:

- Irreversible climate impacts: the probability of irreversible damages; for example, species extinction, increased mortality/morbidity, melting of ice sheets, changes in ocean currents. Even climate effects which are notionally reversible - for example, thermal expansion of the oceans - are effectively irreversible for centuries by human actions.

- Irreversible GHG emissions: the practical inability of having negative GHG emissions which puts limits as to the rate at which future GHG concentrations could be potentially be lowered in the response to extreme impacts.

- Dynamic effects: The long lead times needed to develop new technologies, and the longevity of invested capital, mean that the cost of action is crucially dependent on previous investment decisions.

It should be noted that non-linearities in climate damages - that is, changes in the damage caused per unit of GHG emitted with concentration - do not on their own imply that using stochastic optimisation will produce different results from those found using the mean of the damage distribution. This is because if the future was completely reversible the impact of high damages could be ameliorated without reference to past actions, and the expected value of the system would be equivalent to using the mean of the distribution.

In most analyses - whether numerical or theoretical - the importance of these factors in influencing policy making is assessed by comparing their optimum mitigation and adaptation profile over time with that calculated from best-guesses of the uncertain variables. The impact of irreversibility and dynamics therefore seen as raising or lowering current emissions relative to this base-case scenario.

The resulting policy prescriptions can be highly non-intuitive. For example, recommending higher emissions in the present if there is the potential that we may want to have negative GHG emissions under some potential future damage scenarios (Ulph and Ulph 1994, Mabey *et al* 1997)! However, some generalisations can be made under the assumption of rising marginal damages from emissions:

If GHG emissions and climate damage are effectively irreversible, and /or the development of new mitigation technologies infeasible over a similar time scale to the turnover of existing polluting capital there should be greater and earlier abatement than in a best-guess analysis.

Such ‘precautionary action’ is not dependent on decision makers being risk-averse, but stems purely from a risk-neutral optimal analysis of the problem. Though these results give potentially important policy advice, they are actually highly opaque to policy makers in this form. Policy makers do not start from some “best-guess” or mean scenario of climate damage but from business-as-usual, and so need absolute advice on emission levels and reduction profiles.

Constructing "Optimal" Policies: Assessing Different Influences on Formal Modelling Results

Formal models provide a framework for thinking about how uncertainty and non-linear effects such as thresholds, irreversibility and dynamics interact. However, to be useful in the policy debate these concepts must be translated into everyday language so that negotiators understand the general logic behind different quantitative results, if not the formal models that drive them.

Policy makers must be given frameworks for weighing up the risks associated with both action and inaction, assessing which one is likely to give the best outcome over all possible futures.

A simple approach to showing the upside and downside risks of different polices is given in the table below.

Table 1: Climate Risk Matrix

	Upside Risk	**Downside Risk**
Wait-and-see	If climate damage low mitigation costs saved	If climate damage high irreversible damage caused and extra mitigation and adaptation costs incurred
Stabilise Now	If climate damage high irreversible impacts avoided and mitigation costs minimised	If climate damage low mitigation and adaptation costs incurred.

This type of matrix approach can never explore the full subtleties of the formal models - many of which lie in second and third order effects - but does allow and economic (though not ethical) assessment to be deconstructed into a set of potentially empirical questions:

How large are mitigation costs relative to the range of potential climate change damages?

Though economic analysis of climate damages is in its very early stages, and probabilities mostly unquantified, studies seem to show that a likely range of climate change impacts many times wider than cost estimates of achieving stabilisation at relatively low concentration levels over the next fifty years.

How reversible is climatic change compared to mitigation/adaptation?

Carbon dioxide is estimated to stay in the atmosphere for 100-150 years, and many climate impacts on natural systems will be either completely irreversible or persist for many hundreds of years. On the other hand most response technologies have an economic lifetime of 10-20 years (cars, power stations, industrial equipment), though infrastructure such as town plans, roads, flood defences and water systems are much longer lived (50-100 years).

Does delaying action increase or decrease mitigation costs?
This question is determined by the relative dynamics of capital investment and technological development.

If immediate GHG mitigation measures led to widespread scrapping of the existing capital stock, then short term delay in implementation could save costs. However, the existing capital stock is not of one age, but is continually being turned over. An immediate credible signal that real CO_2 limits were being implemented would give incentives for incremental replacement investments to be energy efficient. If action is delayed companies and individuals may not find incentives credible, and so will continue investing in inefficient technology. If this happens when policies finally are implemented the same questions of capital scrapping will occur, leading to similar arguments for delay. In this way a policy of delay may well be time inconsistent in the incentives it gives to companies and individuals.

Technological progress can be driven by activity which is endogenous or exogenous to markets. If it is assumed that the majority of carbon saving will come from radical new technologies found by government-sponsored research, then delaying any action until they are available would save mitigation costs. However, if most R&D is assumed to be market-driven and carried out by private firms, then delaying action will remove incentives for research, slow the development of new commercial technologies and so raise mitigation costs.

The balance of this - admittedly sparse - evidence points to the risks of damage associated with rising GHG concentrations to be higher, and more irreversible, than the economic risks associated with immediate, significant GHG mitigation and eventual stabilisation. This view is re-enforced if delaying action is seen to slow technological development and the upgrading of capital stocks, as this will greatly reduce future flexibility in responding to climate change. If premature scrapping of the capital stock is seen as a problem then this might force a small delay, or reduction in the level of immediate action; however, the danger of mixed regulatory signals must be taken into account.

This assessment implies that would be economic value for risk-neutral actors in taking precautionary action to preserve future flexibility, even if estimates of mean damages from climate change were near zero. A true "no-regrets" policy must involve implementing measures to a level which involves actual economic costs (discounting local environmental or financial benefits), otherwise policy makers will be purchasing sub-optimal levels of insurance against climate change.

Formal models of decision making under uncertainty do seem to be able to provide useful guidance to policy makers, even when information quality is poor. The real value lies in giving a framework inside which to differentiate and assess - both quantitatively and qualitatively - the importance of different factors. Thus moving the debate into more rational and fruitful territory.

However, the difficulty in providing accurate and robust inputs to such sophisticated methods cannot be underemphasised. Current knowledge of economic factors such as the dynamics of technical progress and capital turnover is as incomplete as our knowledge of specific climate change impacts.

It is also important to expand analysis outside the boundaries of these models to include other harder to estimate, but still vastly important, factors in the policy equation. Otherwise we risk being trapped into a useful, elegant but ultimately incomplete cul-de-sac.

Omissions from Formal Models of Decision Making Under Uncertainty

This section considers three factors which are underexplored, or omitted, from formal models: different ideas of uncertainty and learning; distribution of risk; credibility and time consistency of policy choices. All three will have important impacts on the two questions which policy makers want to answer: What is the optimal timing and level of mitigation and adaptation action? What are the best policy instruments for achieving these goals?

Disaggregating Analysis of Uncertainty from Risk Averse Attitudes

Formal models of decision making reduce all uncertainty to a series of informationally equivalent probability distributions which can be mathematically manipulated. However, in the real world the type of uncertainty surrounding different aspects of climatic change is not identical and cannot always be usefully be described by a probability distribution. It must also be noted that scientific research is seldom designed to generate the type of probabilistic estimates needed by these decision procedures. If quantitative modelling is to inform policy makers attention must be paid as to how to encourage the generation of such types of information by the scientific community.

Uncertainty can be divided into three types:

Inaccuracy: The process under study is ultimately knowable, but current understanding and measurement is incomplete; for example, methane emissions from warming tundra, carbon absorption by the oceans.

Randomness: Processes are so complex (perhaps even chaotic) that they will never be described more fully than by a probability distribution; for example, regional rainfall patterns, the temperature dependence of fish stocks.

Ignorance: Processes are either so unknown, or badly understood at the present time, that no meaningful probability distribution may be put upon them; for example, the reaction of major ocean currents to climatic change.

The first two types are often called “soft” uncertainty because they can be described statistically, while ignorance is termed “hard” uncertainty and is mathematically intractable (Vercelli, 1994). With learning ignorance can be reduced and transformed into soft uncertainty, though research is also likely to uncover new areas of badly understood uncertainty. Though it cannot be accurately incorporated into numerical models, the presence and extent of ignorance must always be considered when making policy decisions.

Formal models of public decision making usually assume risk neutrality unless there is empirical evidence of risk averse or favouring behaviour. However, the existence of hard uncertainty gives support for an *a priori* rational preference for risk averse behaviour by policy makers. In practical terms this means that policy makers will value, and thus be prepared to spend money to achieve, a reduction in the variance of future outcomes above and beyond that recommended by consideration of irreversibilities and threshold effects.

Good decisions under uncertainty are formed out of two processes: optimal decision making under soft uncertainty; and precautionary action to reduce future uncertainty based on a qualitative estimate of the extent of hard uncertainty.

The influence of including hard uncertainty in policy decisions is shown by examining the trade-offs between investing in mitigation or adaptation measures. In modelling the complex interactions of mitigation and adaptation measures it is implicitly assumed that all costs and benefits can be described by equivalent probability distributions. However, this assumption does not hold because the amount of hard uncertainty surrounding the benefits of mitigation (that is, the reduction in climate damage due to a slower rise in GHG concentrations) is much lower than that around adaptation measures.

Most adaptation measures are dependent on ameliorating local climatic changes. This is relatively straight forward when considering new air conditioning loads but is far more uncertain when longer term investments in sea defences, water systems and agricultural practices are being planned. The local or regional climate which determines the effectiveness of adaptation is governed by both hard and soft uncertainty. Many local changes will exhibit true randomness, and so will never be even statistically described until a new climatic equilibrium is reached. Meanwhile, decision makers must invest in long lasting adaptive technologies without knowing the true extent of changing storm surges, new rainfall patterns and unknown pest and disease variations.

In contrast the link between GHG emissions and climate change is understood, if not fully, and so the positive impact of mitigation actions can be assumed with reasonable confidence. Therefore, good policy should involve investing relatively more in mitigation than quantitative models would recommend.

Optimal Policies and Risk Distribution

General theories of decision making under uncertainty implicitly assume that the output of the system they are optimising can be unambiguously expressed in terms of a single numeraire. While an appropriate assumption for business decisions, it is an unacceptable oversimplification for public policy purposes. The UNFCCC explicitly mentions the need to balance risk between different countries (intra-generational equity) and across generations (the sustainability principle). Therefore, considerations of risk distribution cannot be discounted when assessing formal modelling of optimal decisions (Mabey *et al*, 1997).

Those bearing the greatest downside risk from very severe climate impacts are already marginalised subsistence communities, mainly in the tropics. Conversely, the risk of over-investment in climate mitigation is borne by higher income groups which are less dependent on climate vulnerable activities through their participation in the commercial fuel driven economy.

The hypothetical resolution of this distribution dilemma prescribed by classical welfare economics involves direct compensation payments between the two groups to maximise the market value surplus of any policy. There have already been some suggestions that this may occur in the case of the small island states, but no believable commitments have yet been made.

If global compensation is an unlikely political reality, the policy implications of this uneven spread of risk is again to make mitigation options more attractive than adaptation measures. Theoretically this effect could be quantified in a numerical assessment by using a system of agreed weights. However, our limited understanding of the exact distribution of climate impacts will always make such exercises subject to, and eclipsed by, political disputes.

The uneven distribution of climate risk argues for greater risk averse behaviour in formulating climate policies, as opposed to concentration on welfare optimal measures formed under risk neutrality.

Credibility and Time Consistency of Policy Choices

The above discussion has concentrated mainly on how to determine the best choice of mitigation and adaptation measures over time. In general, it has been assumed that policy makers have the power and instruments to implement these recommendations with little reference to external constraints. The only human constraints that have be considered have been the dynamics of the economy in its use and production of capital and technology. Though most models assume a very command-and-control type structure, even when using economic instruments such as carbon taxes.

However, politicians are forced to consider more factors when setting policies which expect significant private sector responses - as any finance minister or central banker will testify. In a dynamic setting, where markets assume politicians will make short term easy choices if they can possibly help it, major economic policy commitments depend on the expectations of markets that they are credible and likely to be carried through.

The arguments for delaying action to avoid capital scrapping is therefore flawed because is will it lack any future credibility. If coal, oil and automobile companies think they will be hurt by targets now, there is no reason why they will not use the same arguments in ten years time when planned reductions are scheduled to be implemented. Unless governments are seen to irreversibly commit to forward policies now - such as, legislation to annually escalate fuel taxes, public investments in energy efficiency or significant lowering of other tax revenues to balance planned pollution tax revenues - private investment in R&D to meet a perceived demand for energy efficient technologies will be too risky. To put it bluntly, it is easier, cheaper and safer for industry to invest $20 million in advertising and lobbying to avoid immediately binding targets, than to invest $500 million in commercialising fuel cells.

The timing of commitments, and the choice of policy instruments, must take into account the need for strong, credible forward signals to be sent to the private sector so that significant changes in investment and technology patterns occur.

Conclusions

Use of formal models of decision making under uncertainty can give many helpful insights as to the important influences on climate policy. Though the state of current knowledge precludes any expectation of them producing reliable quantitative policy recommendations as to targets and timetables.

However, a few strong messages are clear:

- The relative irreversibility of climatic change compared to economic responses creates an option value for controlling GHG emissions. This implies immediate action should go well beyond no-regrets measures.

- The extent of ignorance over climate change impacts, and their uneven distribution, provides a rational argument for risk averse behaviour. A risk averse policy will, all other things being equal, favour mitigation policies over adaptation.

- Changing the economy, and developing new commercial technologies, takes time; which is why it should begin as early as possible. Notwithstanding measures to avoid premature capital scrapping, governments must immediately commit to credible future policies on emissions control if they are to stimulate private sector activity.

Policy Instruments and Uncertainty

In terms of policy instruments there is little clear guidance from the models as to whether command and control or economic instruments are more favoured. Perhaps the strongest messages come in what policies **not** to pursue if flexibility in responding to future knowledge of climate impacts is to be preserved. The wrong messages will be sent if targets are low, ostensibly to prevent economic dislocation, and made up of baskets of emissions. Without clear targets for reducing CO_2 emissions, policies will concentrate on quick technical fixes to reduce methane and

NOx emissions. This will reduce the pressures for planning and initiating longer term changes, and by resulting in “cost savings” lead to a sub-optimal level of investment in flexibility.

The debate over cost minimising instruments - such as baskets, trading and JI - must be firmly linked to discussions over stronger commitments. An overly generous trading system, especially if it includes countries such as Russia which are greatly in surplus, will reduce governmental credibility and encourage continued investment in long lived polluting machinery and infrastructure. Reliance on achieving emissions reductions through technology transfer to developing countries is also unwise in the long term. As it deflects attention from domestic inefficiencies and investments, and is likely to be short lived as newly industrialising countries start to compete in markets for efficient technologies. Using such mechanisms to delay difficult political choices will result in greater costs in the medium term if - as seems likely - the impacts of climate change become clearer and the Kyoto timetable needs to be strengthened and speeded up.

Though much policy analysis has focused on the need to stimulate market responses, especially new technology, it is outside the market sector that many of the most important decisions will be taken. Government controlled planning must take climate issues into account immediately, because they are responsible for many of the longest-lived investments in infrastructure which set the context within which market signals operate. Failing to rectify current subsidies and preference for energy intense land use patterns - for example, in the EU through mechanisms such as reform of transport planning guidelines, structural funds and the CAP - will greatly limit future flexibility and raise the cost of responding to climate change.

In terms of certain and credible policy messages to markets, a system of tradable emission permits at the national level is more likely to stimulate emissions reductions than introducing a broad carbon tax. The risk is that permit prices may rise sharply in the short term (up to the backstop penalty price) if there are dynamic problems in achieving yearly targets; however, the development of futures and options markets, coupled with short (3-5 year) budget periods should ameliorate these problems. In the longer term a tax may promote technologies which overcomply, though a similar set of incentives can be achieved with emissions banking or forward trading of permits.

It is also likely that governments will use existing systems of technology push and pull, combined with efficiency regulations; especially in areas with persistent market failures, such as domestic appliances and transport. However, there is nothing particularly new in these techniques being applied to climate change except in the scale and depth of their application. Reliance on command-and -control approaches should be minimised however where market inefficiencies can be overcome with more flexible instruments which encourage diverse innovation and substitution away from goods - not merely technical improvement of existing consumption patterns. For example, facilitation of low interest loans to finance energy efficiency packages to households, and removal of administrative barriers to integrating different modes of transport such as road and rail.

The message from the analysis above remains clear - there is economic value in retaining future flexibility and options by immediately limiting the use of fossil fuels. The choice of policy targets and instruments must reflect this logic, otherwise using partial models of static cost minimisation will lead to greater damage, mitigation and adaptation costs in the future.

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