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Making Climate Decisions

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Abstract

Many fine-grained (if not bigger picture) decisions concerning climate change involve significant, even severe, uncertainty. Here, we focus on modelling the decisions of single agents, whether individual persons or groups perceived as corporate entities. We offer a taxonomy of the sources and kinds of uncertainty that arise in framing these decision problems, as well as strategies for making a choice in spite of uncertainty. The aim is to facilitate a more transparent and structured treatment of uncertainty in climate decision making.

1. *Introduction*

The decisions that we make in response to climate change have consequences affecting both individuals and groups at different places and times. Indeed, they may even affect what groups or populations exist. Moreover, the circumstances of many of these decisions involve uncertainty and disagreement that is sometimes both severe and wide-ranging, concerning not only the state of the climate and the broader social consequences of any action or inaction on our part, but also the range of actions available to us and what significance we should attach to their possible consequences.

These considerations make climate decision-making both important and hard. The stakes are high, and so too are the difficulties for standard decision theory – plenty of reason for philosophical engagement with this particular application of decision theory. It is unlikely though that there will be a single, simple recipe for handling climate decisions. For one thing, different agents face very different kinds of decisions and do so from quite different perspectives; the problems faced by individual citizens are different from those of national governments or international organisations. Furthermore, many hold that an inherent feature of severe uncertainty and disagreement in a decision problem is that oftentimes we must appeal to principles beyond rationality in order to determine a unique solution, i.e. in order to settle on a final choice of action.

In the first section, we look more carefully at the main actors in the climate domain and the kinds of decision problems that concern them. In the second, we examine the multidimensional nature of the uncertainty that provides the context in which these decisions are made. In the third, we explain why this context confounds standard decision theory and consider plausible responses to this challenge, given that decisions must inevitably be made.

2. *Agents And Climate Decision Problems*

When introducing decision theory, it is common to distinguish three main domains: individual decision theory (which concerns the decision problem of a single agent who may be uncertain of her environment), game theory (which focuses on cases of strategic interaction amongst rational agents) and social choice theory (which concerns procedures by which a number of agents may ‘think’ and act collectively).[1] All three realms are relevant to the climate change predicament, whether the concern is adapting to climate change or mitigating climate change or both.

Determining the appropriate agential perspective and type of engagement between agents is important, because otherwise, decision-modelling efforts may be in vain. For instance, it may be futile to focus on the plight of individual citizens when the power to affect change really lies with states. It may likewise be misguided to analyse the prospects for a collective action on climate policy if the supposed members of the group do not see themselves as contributing to a shared decision that is good for the group as a whole. It would also be misleading to exclude from an individual agent’s decision model the impact of others who perceive that they are acting in a strategic environment. This is not, however, to recommend a narrow view of the role of decision models – that they must always realistically represent the key decisions at hand; the point is rather that we should not employ decision models with particular agential framings in a naïve way.

The general purpose of decision modelling could be to provide an argument, or an exploration of the reasons, for taking particular courses of action. This could be a very *direct* argument – the model might attempt to capture a decision problem that a particular agent (whether an individual or group) *actually faces*, where the idea is to identify the rational/fair course of action, by the agent’s current lights. In this case, it is important to determine, as well as possible, the agent’s current preferences, together with the preferences of any other agents that will impact on decision outcomes. For instance, consider the designing of a proposed emissions trading scheme: to be credible, the consequences of various design options, such as the allocation of carbon allowances, must account for the actual motivations and choice behaviour of various industry players, and the final evaluation of options must account for actual policy concerns (not least the goal for overall emissions reduction).[2]

Alternatively, the argument presented by a decision model might be more *indirect* – the model might present a decision scenario that serves as a contrast or a *reference point* that enables better comprehension of the actual decision setting, and the potential for change. Such a model would identify the rational/fair course of action conditional on certain features that are not necessarily true of the world, perhaps to do with the agents’ preferences or the extent of group cooperation. Global economic analyses of climate change such as the Stern Review or the scenarios presented in the reports of the Intergovernmental Panel for Climate Change (IPCC) may be viewed in this light. The Stern Review (2007), for instance, takes the perspective of a global social planner; to this end, the costs of substantial mitigation of climate change are compared with ‘business as usual’ emissions, where costs are calculated in terms of a time-discounted utilitarian aggregate of individual wellbeing over a time horizon of several centuries.[3] More recently, game theorists have offered alternative state-centred benchmarks for mitigation – models that focus on strategic interaction amongst groups of states, given assumptions about the ‘national interest’ of these respective states.[4]

Getting the agential perspective right is just the first step in framing a decision problem so that it presents convincing reasons for action. There remains the task of representing the details of the decision problem from the appropriate epistemic and evaluative perspective. We turn to this task now. Our focus is individual decision theory, for reasons of space, and because most decision settings ultimately involve the decision of an individual, whether this be a single person or a group.

3. Uncertainty And Disagreement

The standard model of (individual) decision-making under uncertainty used by decision theorists derives from the classic work of von Neumann and Morgenstern (1944) and Leonard Savage (1954). It treats actions as functions from possible states of the world to consequences, these being the complete outcomes of performing the action in question in that state of the world. Fig. 1 depicts an abstract decision problem in line with this model, in typical tabular style, with rows representing actions (here A_1 and A_2), columns representing states of the world (here S_1, S_2 and S_3) and table entries representing the consequences associated with each action and state pair (here $O_{1,1}$, …, $O_{2,3}$). All uncertainty is taken to be uncertainty about the state of the world and is quantified by a single probability function over the possible states, where the probabilities in question measure either objective risk or the decision maker's degrees of belief (or a combination of the two). The relative value of consequences is represented by an interval-scaled utility function over these consequences. Decision makers are advised to choose the action with maximum *expected utility* (EU), where the EU for an action is the sum of the probability-weighted utility of the possible consequences of the action.[5]

It is our contention that this model is inadequate for many climate-oriented decisions, because it fails to properly represent the multidimensional nature and severity of the uncertainty that decision makers face. To begin with, not all the uncertainty that climate decision makers face is empirical uncertainty about the actual state of the world (state uncertainty). There may be further empirical uncertainty about what options are available to them and what are the consequences of exercising each option for each respective state (option uncertainty). Furthermore, decision makers face a non-empirical kind of uncertainty – ethical uncertainty – about what values to assign to possible consequences.[6] Before elaborating on these different *facets* of uncertainty, however, let us briefly comment on the general *sources* of uncertainty.

One source of uncertainty in climate decision models is simply our epistemic limitations, ultimately the limitations of our current best science. There are (potentially irresolvable) scientific limitations to projections of future climate under the various conceivable emissions scenarios. This is compounded by broader scientific, and especially social scientific, uncertainty about the effects of climate changes on the constituents of human wellbeing, such as food production and health, which may be even more severe in virtue of depending on estimates of human responses to climate change. In general, the more detailed the information the decision maker seeks, in spatial, temporal or other empirical terms, the greater the scientific uncertainty. The upshot is that science cannot deliver the precise probabilistic predictions that are required for many applications of standard decision theory.

The other source of uncertainty in climate decision-making is expert disagreement. One might think that there is inevitably disagreement where there is scientific uncertainty, but the two do not amount to the same thing: indeed, there may be more or less disagreement amongst scientists about the nature and extent of scientific uncertainty about a particular empirical claim. Beyond that, there is of course scope for reasonable disagreement amongst experts on non-empirical issues, in particular the relative goodness of possible decision consequences. Disagreement of this sort manifests in social debate about the aims of climate policy interventions or the standards by which they should be judged.[7] While different in character, disagreement has a similar upshot for decision modelling as scientific uncertainty: it fails to deliver a precise representation of the decision problem as required by standard decision theory.

STATES **ACTIONS**	S_1	S_2	S_3
A_1	$O_{1,1} = A_1(S_1)$	$O_{1,2} = A_1(S_2)$	$O_{1,3} = A_1(S_3)$
A_2	$O_{2,1} = A_2(S_1)$	$O_{2,2} = A_2(S_2)$	$O_{2,3} = A_2(S_3)$

Fig. 1. Abstract decision problem in tabular form.

3.1. EMPIRICAL UNCERTAINTY

As noted above, standard decision theory holds that all empirical uncertainty can be represented by a probability function over the possible states of the world. There are two issues here: (i) confining all empirical uncertainty to the state space is rather unnatural for complex decision problems such as those associated with climate change, and (ii) using a precise probability function to represent uncertainty about states (and consequences) can misrepresent the severity of this uncertainty, whether it stems from scientific limitations or disagreement or both.

On the first point, the idea is that decision models are less convoluted if we allow the uncertainty about states to depend on the actions that might be taken,[8] and if we also permit further uncertainty about what consequence will arise under each state, given the action taken. For instance, consider a crude version of the mitigation decision problem faced by the global planner: it may be useful to depict the decision problem with a state-space partition in terms of possible increases in average global temperature (AGT) over a given time period, as per Fig. 2. In this case, our beliefs about the states (how likely they each are) would be conditional on the mitigation option taken. Moreover, for each respective mitigation option, the consequence arising in each of the states plausibly depends on further uncertain features of the world; for instance, the extent to which, on average, regional conditions would be favourable to food production and whether social institutions would facilitate resilience in food production. (In Fig. 2 below, the probability distribution over food production outcomes indicated by the random variable X plausibly differs for each consequence entry in the table, i.e. for each act–state combination.)

Besides permitting more elegant decision models, the distinction between state uncertainty and option uncertainty with respect to consequences may be useful for tracking at least some of the compounding uncertainty associated with predictions of climate change impacts. In general, it is useful to structure uncertainty about climate change impacts in terms of a hierarchy, where the severity of uncertainty increases as we go downwards (cf. Heal and Millner 2014): the less 'basic' the issue, in terms of scientific priority, and/or the more 'refined' the prediction required, in spatial/temporal terms, the further down we are in the uncertainty hierarchy, i.e. the more severe the uncertainty. Thus, towards the top, we have *coarse* global average estimates of *basic* climate variables like temperature or precipitation. Further down the hierarchy, we have *finer* regional estimates of these climate variables as well as other *less basic* climate and ecological variables, until ultimately we reach estimates of detailed socioeconomic variables. One modelling proposal is that the state space covers possibilities in the top half of the hierarchy while the consequence space includes possibilities in the bottom half of the hierarchy. The uncertainty at these two loci might even be 'managed' differently in non-standard decision theories.[9] An important question in this regard is whether there is, or need be, a principled way of making this state-space/consequence-space division.

	1-2℃ rise in AGT	2-3℃ rise in AGT	3-4℃ rise in AGT	4-5℃ rise in AGT
Mitigation 1	Disruption in food production of order $X_{1,1}$	Disruption in food production of order $X_{1,2}$	Disruption in food production of order $X_{1,3}$	Disruption in food production of order $X_{1,4}$
Mitigation 2	Disruption in food production of order $X_{2,1}$	Disruption in food production of order $X_{2,2}$	Disruption in food production of order $X_{2,3}$	Disruption in food production of order $X_{2,4}$

Fig. 2. Mitigation decision model where state likelihoods depend on acts, and moreover, there is not a determinate consequence associated with each act-state pair.

The second issue is that at least some of this empirical uncertainty may not be adequately expressed in terms of precise probabilities over states and/or consequences. With regard to the model in Fig. 2, for instance, the position of the scientific community may be reasonably well represented by a precise probability distribution over the state space, conditional on the mitigation option, but precise probabilities over the possible food productions, given this option and average global temperature rise, are less plausible. Popular amongst philosophers is the use of sets of probability functions. This is a minimal generalisation of the standard decision model, in the sense that probability measures still feature, roughly, the more severe the uncertainty, the more probability measures over the space of possibilities needed to conjointly represent the epistemic situation.[10] See Halpern (2003) for a thorough treatment of frameworks, both qualitative and quantitative, for representing uncertainty.

There is arguably a further aspect to option uncertainty that is overlooked in standard decision theory: uncertainty about what acts/options are actually available to the decision maker. Indeed, one of the greatest difficulties facing climate decision makers is how to form expectations about technological developments that might assist in mitigating the effects of climate change or in adapting to it. The IPCC (2014a) ARC-5 WGIII report, for instance, acknowledges that mitigation costs are greatly dependent on future technological options, in particular, options for enhanced energy efficiency and reduced carbon intensity of energy production. Of course, one might contest that any such option uncertainty merely indicates a flawed decision model; for example, apparent uncertainty about whether the option 'mandate solar-powered cars' is feasible simply reveals that the *actual* available option is rather 'support research on affordable solar cars'. But why should all empirical uncertainty in a decision model, particularly where this uncertainty is severe, be relegated to the state space, rather than also be distributed over the act space as well as the consequence space associated with each act–state pair? Of course, the question remains as to whether there is, or need be, a principled way to sort uncertainties in this manner.

3.2. ETHICAL UNCERTAINTY

Decision makers face uncertainty not only about what will or could happen but also about what value to attach to these possibilities. Such value or ethical uncertainty can have a number of different sources. Some of it may be essentially empirical, such as when we don't know what value to attach to a car because we are unsure as to how safe it is or what speeds it can obtain. Another source, also ultimately empirical in nature, is uncertainty about preferences, either our own (future) ones or those of others affected by our decisions. This is a common problem in decisions with broad spatial and temporal ramifications (consider buying a present for someone's birthday several years in advance). Finally, there is non-empirical or *pure* ethical uncertainty that arises when trying to value completely specified objects or outcomes. One might, for instance, have complete information about the attributes of the car one is evaluating but be unsure what weight to put on these attributes, how to trade off safety and speed for example.

Ethical uncertainty, including the pure kind, arises in many aspects of climate decision-making; for instance, in judgements about how to distribute the costs and benefits of mitigation amongst different regions and countries, about how to take account of persons whose existence depends on what actions are chosen now and about the degree to which future wellbeing should be discounted. Of these, the latter has been the subject of the most debate, because of the extent to which (the global planner's) decisions about how drastically to cut carbon emissions are sensitive to the discount rate used in evaluating the possible outcomes of doing so. In Weitzman's words (2007, 705), 'In fact it is not an exaggeration to say that the biggest uncertainty of all in the economics of climate change is the uncertainty about which interest rate to use for discounting.' Discounting thus provides a good illustration of the importance of ethical uncertainty.

Many climate decisions have long temporal horizons in that comparing the relevant options depends on consequences that stretch far into the future. Inevitably, therefore, decision makers must balance the interests of the current generation against future ones. In economic models, this is reflected in a discount rate applied to a measure of total wellbeing at different points in time (the 'pure rate of time preference'), with a positive rate implying that future wellbeing carries less weight in the evaluations of options than present wellbeing.[11] Many philosophers regard any pure discounting of future wellbeing as completely unjustified from an objective point of view. This is not to deny that temporal location may nonetheless correlate with features of the distribution of wellbeing that are in fact ethically significant. If people will be better off in the future, for instance, it is reasonable to be less concerned about their interests than those of the present generation, much as one might prioritise the less well off within a single generation. But the mere fact of a benefit occurring at a particular time cannot be relevant to its value, at least from an impartial perspective.

Economists do nonetheless often discount wellbeing in their policy-oriented models, although they disagree considerably about what pure rate of time preference should be used. One view, exemplified by the Stern Review and representing the impartial perspective described above, is that only a very small rate (in the order of 0.5%) is justified, and this on the grounds of the small probability of the extinction of the human population. Other economists, however, regard a partial rather than an impartial point of view more appropriate in their models. A view along these lines, exemplified by Nordhaus (2007) and Arrow (1995a), is that the pure rate of time preference should be determined by the preferences of current people.[12] The current generation does of course care about future generations, as is evident in the fact of its willingness to support infrastructural expenditure with long-time horizons and in individual bequests to the next generation. But typical derivations of average pure time discounting from observed market behaviour are much higher than those used by Stern (around 3% by Nordhaus's estimate). Although the use of this data has been criticised for providing an inadequate measure of people's reasoned preferences, the point remains that any plausible method for determining the current generation's attitude to the wellbeing of future generations is likely to yield a rate higher than that advocated by the Stern Review. To the extent that this debate about the ethical basis for discounting remains unresolved, there will be ethical uncertainty about the discount rate in climate policy decisions.

4. *Managing Uncertainty*

How should a decision maker choose amongst the courses of action available to her when she must make the choice under conditions of severe uncertainty? The problem that climate decision makers face is that, in these situations, the precise utility and probability values required by standard EU theory may not be readily available.

There are, broadly speaking, three possible responses to this problem. Firstly, the decision maker can simply bite the bullet and try to settle on precise probability and utility judgements for the relevant contingencies, doing the best that she can under the circumstances. Secondly, the decision maker can try to delay making a decision, or at least postpone parts of it, in the hope that her uncertainty will become manageable as more information becomes available, or as disagreements resolve themselves through a change in attitudes. Finally, the decision maker can make use of a different decision rule to that prescribed by EU theory, one that is much less demanding in terms of the information it requires. This is the response that has been the focus of much recent work in decision theory.

4.1. REACHING A JUDGEMENT

Orthodox decision theorists argue that rationality requires that decisions be made as if they maximise the decision maker's subjective expectation of benefit relative to her precise degrees of belief and values. So precise doxastic and evaluative judgements (whether explicit or not) are mandatory, on pain of irrationality, irrespective of the circumstances in which the decision is made. Broome gives an unflinching defence of this approach:

> The lack of firm probabilities is not a reason to give up expected value theory. You might despair and adopt some other way of coping with uncertainty … That would be a mistake. Stick with expected value theory, since it is very well founded, and do your best with probabilities and values. (2012, 129)

We will canvas an opposing view below in Section 4.3. But in any case, there remains the question of how to follow Broome's advice: how should the decision maker settle, in a non-arbitrary way, on a precise opinion on decision-relevant issues in the face of an effectively 'divided mind'? There are two interrelated strategies: she can deliberate further and/or aggregate conflicting views. The former aims for convergence in opinion, while the latter aims for an acceptable compromise in the face of persisting conflict.

Deliberation is generally thought to involve iterative exchange, examination and weighing of reasons, and consequent revision of opinion. There is some debate amongst scientists as to whether deliberation in various contexts really does improve the quality of opinions, much less lead to agreement.[13] In any case, when deliberation fails to result in consensus, we must appeal to some method for aggregating different viewpoints. Two basic approaches to aggregation are particularly salient: voting rules choose the 'best' opinions from amongst the available ones, while averaging rules (such as 'splitting the difference' and linear averaging) form aggregate opinions that are compromises between the individual ones. In the latter case, there is a question of what weight to accord each individual viewpoint. When there is no reason for favouring one opinion over the others, the principle of insufficient reason dictates treating each equally. But the literature recognises a great variety of contexts in which considerations favour discriminatory treatment of the various viewpoints.[14]

4.2. POSTPONING THE DECISION

The second possible response that is available to decision makers, at least in some contexts, is to delay all or part of the decision until more information is available or some of the disagreement is resolved. Not surprisingly, this response is rather popular amongst politicians who would rather not be held responsible for decisions that impose costs on their constituencies. For the same reason, it is held in low regard by those most concerned about the effects of climate change. Some distance from the political heat is therefore required in order to consider the advantages and disadvantages of delaying decisions.

The basic motive for delaying a decision is to maintain *flexibility* at zero cost (see Koopmans 1962, Kreps and Porteus 1978, Arrow 1995b). Suppose that we must decide between building a cheap but low sea wall or a high, but expensive, one, and that the relative desirability of these two courses of action depends on unknown factors, such as the extent to which sea levels will rise. In this case, it would be sensible to consider building a low wall first but leave open the possibility of raising it in the future. If this can be done at no additional cost, then it is clearly the best option: at worst, no new information is acquired by the time the low wall is completed and you are in much the same situation as you started; at best, you are able to make the optimal choice at the later time. In many adaptation scenarios, the analogue of the 'low sea wall' may in fact be social-institutional measures that enable a delayed response to climate change, whatever the details of this change turn out to be. When it comes to long-term water planning, for instance, it may be optimal to initially strengthen systems of governance for water distribution and usage in order to accommodate any change in supply, and only later decide on further measures that depend on predictions about the nature of the change in supply.[15] In many cases, however, the prospect of cost-free postponement of a decision (or part thereof) is simply a mirage, since delay often decreases rather than increases opportunities due to changes in the background environment. This is often true for climate change adaptation decisions, not to mention mitigation decisions. The extent of the benefit of delaying will depend on the possibilities for sufficiently limiting these costs by breaking the original decision problem down into relatively autonomous, subsidiary decision problems that can be settled sequentially.

4.3. ALTERNATIVE DECISION RULES

The third strategy to consider is that of applying an alternative decision rule to that of maximising expected utility, one that is tailored to situations of severe uncertainty. A great many different proposals for such rules exist in the literature, involving more or less radical departures from the orthodox theory and varying in the informational demands they make. Our focus will be on rules that handle state and ethical uncertainty[16]; in particular, we focus on rules that take as inputs the set of all permissible pairs of probability and utility functions characterising the decision maker's uncertainty. We regard these rules as candidates for rational choice, i.e., as challenges to the notion that rational agents must abide by all the dictates of EU theory.

It should be noted from the outset that there is one widely agreed rationality constraint on these non-standard decision rules: '(EU)-dominated options' are not admissible choices, i.e., if an option has lower expected utility than another option according to all permissible pairs of probability and utility functions, then the former dominated option is not an admissible choice. This is a relatively minimal constraint, but it may well yield a unique choice of action in some decision scenarios. In such cases, the severe uncertainty is not in fact decision-relevant. For example, it may be the case that, from the global planner's perspective, a given mitigation option is better than continuing with business as usual, whatever the uncertain details of the climate system. This is even more plausible to the extent that the mitigation option counts as a 'win-win' strategy (Maskin and Austin 2012), i.e., to the extent that it has other positive impacts, say, on air quality or energy security, regardless of mitigation results. In many more fine-grained or otherwise difficult decision contexts, however, the non-EU-dominance constraint may exclude only a few of the available options as choice-worthy.

A consideration that is often appealed to in order to further discriminate between options is *caution*. Indeed, this is an important facet of the popular but ill-defined Precautionary Principle.[17] Cautious decision rules give more weight to the 'down-side' risks, the possible negative implications of a choice of action. The Maxmin-EU rule, for instance, recommends picking the action with greatest minimum expected utility (see Gilboa and Schmeidler 1989, Walley 1991). The rule is simple to use, but arguably much too cautious, paying no attention at all to the full spread of possible expected utilities. The α-Maxmin rule, in contrast, recommends taking the action with the greatest α-weighted sum of the minimum and maximum expected utilities associated with it. The relative weights for the minimum and maximum expected utilities can be thought of as reflecting either the decision maker's pessimism in the face of uncertainty or else their degree of caution (see Binmore 2009).[18]

A more informationally demanding set of rules are those that draw on considerations of *confidence* and/or *reliability*. The thought here is that an agent is more or less confident about the various probability and utility functions that characterise her uncertainty. For instance, when the estimates derive from different models or experts, the decision maker may regard some models as better corroborated by available evidence than others or else some experts as more reliable than others in their judgement. In these cases, it is reasonable, ceteris paribus, to favour actions of which you are more confident that they will have beneficial consequences. One (rather sophisticated) way of doing this is to weight each of the expected utilities associated with an action in accordance with how confident you are about the judgements supporting them and then choose the action with maximum confidence-weighted (transformed) expected utility (see Klibanoff et al. 2005). This rule is not very different from maximising expected utility, and indeed, one could regard confidence weighting as an aggregation technique rather than an alternative decision rule. But considerations of confidence may be appealed to even when precise confidence weights cannot be provided. Gärdenfors and Sahlin (1982), for instance, suggest simply excluding from consideration any estimates that fall below a reliability threshold and then picking cautiously from the remainder. Similarly, Hill (2013) uses an ordinal measure of confidence that allows for stake-sensitive thresholds of reliability that can then be combined with varying levels of caution.

One might finally distinguish decision rules that are cautious in a slightly different way – that compare options in terms of 'robustness' to uncertainty. Better options are those that are more assured of having an expected utility that is good enough or regret-free, in the face of uncertainty.[19] Recall that the uncertainty in question may be multi-faceted, concerning probabilities of states/outcomes, or values of final outcomes. Most decision rules that appeal to robustness assume that a best estimate for the relevant variables is available (perhaps achieved by one of the methods described in Section 4.1) and then consider deviations away from this estimate. A robust option is one that has a satisfactory expected utility relative to a class of estimates that deviate from the best one to some degree; the wider the class in question, the more robust the option. Much depends on what expected utility level is deemed satisfactory, but roughly speaking, in the context of climate change decisions, robust options are those that yield reasonable outcomes for all the inopportune climate scenarios that have non-negligible probability given some range of uncertainty. In the case of adaptation, these are plausibly options that focus on resilience to any and all of the aforesaid climate scenarios, perhaps via the development of social institutions that can coordinate responses to variability and change.[20]

5. *Conclusion*

Climate change decisions evidently raise important challenges for the application of standard expected utility theory. This is in part due to the circumstances of multidimensional, severe uncertainty and in part due to the public nature of many climate decisions, which comes with the demand for fully explicable and reason-based choices. Our aim here is not to advocate any particular position regarding what rationality ultimately requires/permits in these circumstances, but rather to encourage decision modellers to think broadly about the possibilities for framing decision problems and justifying the corresponding choices, and to make their analyses as explicit as possible.

At the more basic level, our discussion demonstrates that proper handling of the uncertainty in decision-making is a matter of careful scientific and practical reasoning. Uncertainty does not amount to *absence of reason* for engaging with a decision problem. Indeed, continuing with the status quo may well be a highly risky option in the face of uncertainty. We have also seen that not all decisions are equally threatened by uncertainty. Roughly speaking, the more fine-grained the decision, in terms of the nature of the competing options and the contingencies that their comparative evaluations depend upon, the more uncertainty complicates choice, and thus the more one confronts controversies in decision-making.

Short Biographies

Richard Bradley is a professor of Philosophy in the Department of Philosophy, Logic and Scientific Method at London School of Economics and Political Science. Richard works mainly in decision theory, social choice theory and formal epistemology and semantics (especially conditionals). He is currently working on a book on decision making under conditions of severe uncertainty, which aims to provide a decision theory suitable for rational but bounded agents.

Katie Steele received her PhD at the University of Sydney and is now an associate professor in Philosophy at London School of Economics and Political Science (LSE). She is also an affiliate of the Grantham Research Institute on Climate Change and the Environment at the LSE and a member of the 'Managing Severe Uncertainty' project, together with colleagues in Philosophy. Her research concerns rational choice and inference and the interface between science and policy.

Notes

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[1] See, for instance, Resnik (1987) for further preliminary discussion of these key domains of rational choice theory.

[2] Hepburn et al. (2006) well illustrate this kind of decision analysis – they investigate the auctioning of carbon allowances within the European Union Emissions Trading System (EU ETS) Phase II.

[3] See Frisch (2013), however, for a skeptical account of the role that 'integrated assessment models (IAMs)', including the one underpinning the Stern Review, can play in policy making, due to their opacity and false precision.

[4] See Tavoni (2013) for a brief summary of the game theoretic perspective on mitigation, including references to key recent works.

[5] See, for instance, Resnik (1987), for a primer on expected utility theory.

[6] See Hansson (1994) for a slightly different typology of uncertainty.

[7] Note that scientific uncertainty and disagreement can compound on each other: for instance, ethical disagreement about best policy within a community plausibly leads to social scientific uncertainty about the evolution of relevant policy instruments and institutions.

[8] Cf. Richard Jeffrey's (1965) expected utility theory.

[9] See, for instance, the decision rule proposed by Walker and Dietz (2011), which treats state and option uncertainty differently.

[10] For early discussions of so-called *imprecise probabilities*, see Levi (1974, 1986), Gärdenfors and Sahlin ([1982] 1988), Bewley (1986/2002) and Walley (1991).

[11] Note that the overall 'social discount rate' in economic models involves other terms besides the pure rate of time preference; these other discounting terms apply to goods or consumption rather than wellbeing per se. See Broome (1992) and Parfit (1984) for helpful discussions of the reasons for discounting *goods* that do not imply discounting *wellbeing*.

[12] See also Beckerman and Hepburn (2007) for ethical arguments supporting a partial orientation towards the pure rate of time preference.

[13] Fishkin and Luskin (2005) canvas criticisms of deliberation (that it is futile or else harmful) and provide some empirical evidence to the contrary.

[14] There are various expositions of the aggregation problem for different types of opinions, whether probabilistic beliefs, paired probabilities and utilities, overall preferences or more general binary judgments: see, for instance, Genest and Zidek (1986), Mongin (1995), Sen (1970) and List and Puppe (2009). There is a comparatively small formal literature on deliberation, a seminal contribution being Lehrer and Wagner's (1981) model for updating probabilistic beliefs.

[15] Wilby and Dessai (2010) discuss resilience and list various such measures for water planning. Here, we draw attention to those resilience initiatives that are part of a broader adaptation strategy and enable cost-free delay of more risky choices (e.g. to do with expensive infrastructure projects). In other cases, 'resilience strategies' are better understood as compromises or 'robust' options in the face of uncertainty (as discussed below in Section 4.3).

[16] We leave aside option uncertainty. See Ghirardato (2001) for a treatment of it.

[17] The Precautionary Principle is referred to in the latest IPCC (2014b) ARC-5 WGII report. See Steele (2006) and the recent Steel (2015) for discussion of what the Precautionary Principle stands for.

[18] For a comprehensive survey of non-standard decision theories for handling severe uncertainty in the economics literature, see Gilboa and Marinacci (2002).

[19] The 'information-gap theory' developed by Ben-Haim (2001) provides one formalisation of this basic idea that has proved popular in environmental management theory.

[20] Robust decision-making is endorsed, for instance, by Dessai et al. (2009) and Wilby and Dessai (2010), who indeed associate this kind of decision rule with resilience strategies. See also Linkov et al. (2014) for discussion of resilience strategies vis-à-vis risk management.

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