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Uncertainty about uncertainty: the futility of benefit-cost analysis for climate change policy

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Abstract
The moral argument for aggressively mitigating continued greenhouse emissions is very strong. The economic case is not as clear, however, owing to great uncertainty about the benefits and costs. Three distinct types of uncertainty – predictive, valuational, and moral – hamper and severely limit the usefulness of social benefit-cost analysis by introducing irreducible subjectivity into the analysis. The complex nature of climate change compels us to rethink the role of economics in policy and better balance it with qualitative reasoning and judgment.

Keywords climate change, uncertainty, subjectivity, social benefit-cost analysis, social discount rate, ethics

1. Introduction

Mounting evidence that anthropogenic climate change is a true phenomenon by now seems irrefutable. While climate and earth scientists have long been calling attention to indicators that climate change is caused by humans, economists have also recently grown more concerned. Yet in their case, the science behind climate change or its likelihood and extent has been of only secondary – albeit hardly peripheral – interest. The primary focus for economists has been on the potential social benefits and social costs of addressing climate change.

Many economists find climate change to be a minor problem when compared to other challenges like hunger or promoting global trade.[1] The belief largely stems from unrealistic assumptions about the modest impact on the global economy of disruptions in agricultural production, as well as about the likely economic consequences of even extreme temperature increases (see, e.g., Nordhaus and Boyer, 2000). But this is not all. The publication of Nicholas Stern's (2007) Review, which claims that the social benefit of aggressive climate change policy is about 100 times greater than that estimated by Nordhaus, helped spark a debate among economists. The social discount rate, to be discussed in detail later, is at the center of this disagreement.

Growing awareness and recognition of the problem of climate change has recently opened the door to at least the possibility of substantive progress in policy. The landmark multinational agreement at the December 2015 Paris Summit (hereafter the Paris Agreement) is an especially welcome sign after decades of prevarication. Yet it is merely a first step, and much of what happens in the future regarding climate change depends on the resolve of policymakers in making the necessary sacrifices to comply with the agreement. Morgan (2016) indeed questions whether there we have seen any fundamental change that could

[1] See e.g., Cline (2004), Nordhaus (2007), and Tol (2003, 2009). Cline and Tol are among a panel of experts (including a few Nobel laureates) that form the Copenhagen Consensus think tank. It is possibly the most notable purveyor of the notion that climate change is relatively unimportant compared to other global challenges.

translate the conditional success of the Paris Agreement to an actual success that might realize its goals.

The degree of commitment of national leaders will, in the long run, come down to their perception of the relevant benefits and costs. This is the principal concern in this paper. I argue that while the evidence in support of climate change is convincing, attempting to gain an unrealistically *precise* understanding of the benefits and costs of ameliorative policy for use in social benefit-cost analysis is potentially worse than useless. Even with a superior understanding than we presently have, we would still not know what dollar values to put on the relevant benefits and costs of climate change policy. And even if we surmounted this obstacle, there is no objective basis for a rate at which to discount benefits and costs into the future. Quantitative precision is likely, therefore, to lead us astray. The challenge, ultimately, will be about coming to recognize that ethics, politics, and other subjective considerations may trump crude economic analysis in determining the appropriate climate policy.

2. What do we mean by uncertainty?

Mitigation vs adaptation

Thirty to forty years ago, climate change (then referred to as 'the greenhouse effect' or 'global warming') was mostly considered a fringe topic. Skepticism prevailed, and those believing climate change to be a real phenomenon tended mostly to see it as a long-term problem. Even today, despite incontrovertible evidence supporting the reality and the imminence of climate change, uncertainty over the details has sustained purveyors of the notion that the idea is a hoax.

There is no shortage of detailed evidence that climate change is happening; it can be found in the numerous quantitative studies that have been published in recent years (Hansen and Sato, 2016; Pachauri and Reisinger, 2007). Yet given the massive economic sacrifice potentially implied by aggressive mitigation policy, the institutional pressure to obfuscate – referred to by Best (2012) as 'bureaucratic ambiguity' – is understandable.[2] Along similar lines, the idea that we cannot avoid either economic or environmental 'pain' in the future is an example of what Rayner (2012) calls 'uncomfortable knowledge' which, he argues, calls for a strategic mix of denial, dismissal, diversion, and displacement.[3]

While there may be no way of *unequivocally* linking massive floods, storms, and droughts in recent years to climate change, many nevertheless regard such events as sufficient circumstantial evidence in support of the climate change hypothesis. In statistical parlance, we might say that the climate change hypothesis has over the past 40 years switched from

[2] Obfuscation on matters of policy importance often – if paradoxically – take the form of quantitative (though often inaccurate) precision on a subset of relevant factors. Substantial uncertainty underlying climate change is concealed through the misleading use of precise figures. For more on this, see also Torras and Surie (2015).
[3] So, for example, the scandal over some ostensibly counterfactual emails suppressed by scientists supports efforts to deny the reality of climate change; undue emphasis on a recent retraction by the Intergovernmental Panel on Climate Change (IPCC) of its own overestimates of the rate of Himalayan glacial melt is an example of diversion. For detailed discussion on the subtle differences, see Rayner (2012).

'alternative' to 'null.' There is indeed no clearer sign of increasingly widespread acceptance of the hypothesis than the Paris Agreement of December 2015.[4]

The natural conclusion would appear to be that we should now be aggressively limiting further carbon emissions, at least until it could be demonstrated that doing so would not be worthwhile.[5] Yet it is one thing to accept science's interpretation of the evidence; it is quite another to claim to know things about future benefits and costs that we simply do not. For example, *how much* will climate change in terms of, say, average global temperature, and how long will it take to do so? What will be the effects on human societies? What can we expect to be the extent of the overall damage? Finally, and possibly most important, is catastrophic, even human-extinguishing, change possible – and if so, with what probability?

We have no unambiguous answers to these important questions. It is not even clear that we are, over time, approaching answers.[6] Climate change studies and data abound, but we can mostly only speculate on how they should be interpreted. Skeptics are actually correct in stating that *we do not know* if sacrifice today – in terms of reducing material and energy flows, slowing down the economy, etc. – would be 'worth it' in the long run. We might naturally assume that aggressive mitigation is vital and urgent (and, ethically speaking at least, such a claim would seem beyond reproach), but from an economic standpoint, it *could* make more sense to instead invest in adaptive technologies – dikes and seawalls, floating cities, etc. – aimed at ensuring survival.

Such a perspective confronts the uncomfortable possibility that substantial future damage is already irreversible. Would it not then be more economical and practical to spend money preparing for higher sea levels and hotter temperatures? While defense of a continued 'business as usual' strategy (hereafter BAU) – i.e., doing nothing now and adapting to climate change in due course – might mostly be politically motivated, unequivocal hard evidence to plausibly challenge it remains elusive.

The net benefit of climate change policy

Some researchers (e.g., Ackerman and Munitz, 2016; Hope, 2008) seek to reliably approximate the true social cost of carbon (SCC) as a basis for tax policy on continued carbon emissions. The problem with a tax is that it merely changes incentives but fails to strictly limit emissions. There is, therefore, no way of ensuring that any given emissions threshold is not breached as a consequence of an insufficiently large tax.

Because of this rather serious limitation, many prefer the alternative of a tradable carbon permits scheme. But there are also problems with a tradable permits system, such as fairness in the permit allocation or ensuring compliance with emissions limits. In theory, the tax on a unit of carbon emitted should equal the price of a permit to emit a unit, though in practice this

[4] Recognition of the problem is, sadly, one small step in addressing it. Ertürk and Whittle (2015) argue that rich and poor countries have different incentives, with the former wanting to export mitigation costs to the latter instead of bearing most of the responsibility. Spash (2016) notes the inconsistency between the Paris Agreement and national governments' commitment to economic growth at all costs.
[5] That emissions of methane, CFCs, and other greenhouse gases should also be severely curtailed hardly bears mentioning. Rather than repeating this point, the reader should consider my mention of carbon as meaning the carbon equivalent of the different greenhouse gases.
[6] This is increasingly recognized by establishment economists such as Nicholas Stern (2013), who argues that the dominant economic modeling approach is likely to seriously underestimate the downside risks associated with climate change.

is unlikely. Nevertheless, the debate over which is better is beyond our present scope. I am interested in the question of how we decide on the proper balance between mitigating and waiting (adapting), independent of the policy mechanisms chosen.

Economists frequently rely on social benefit-cost analysis to evaluate policy options, and here it is helpful to look at how the problem is often framed. Consider the following net benefit function,

$$NB = \sum_{t=1}^{\infty} \frac{B_t[\phi_t(\mu_t), \tau_t(\alpha_t)] - \mu_t - \alpha_t}{(1+d)^t} \tag{1}$$

where NB stands for the discounted sum of social (or global, if you like) net benefits over time.

In this equation, μ_t represents mitigation cost and α_t adaptation cost, both in time *t*. The benefits from climate change policy (B_t) are a function of ϕ_t, which stands for the diminution in climate change compared to BAU, and τ_t, a measure of the extent to which we technologically adapt to climate changes (e.g., hotter temperatures, higher sea levels). ϕ_t and τ_t are, respectively, functions of μ_t and α_t.[7] Finally, *d* represents the social discount rate.

In theory, if the net benefit were positive – i.e., if Equation 1 had a value greater than zero – it would suggest that the specified combination of mitigation and adaptation policy is worthwhile. A negative value would imply the inverse, namely that we would have spent too much money and that BAU would have been better. The problem – and it is a big one – is that there are an *infinite number of possible* ϕ's, depending on the magnitude, balance, and timing of both mitigation and adaptation policies.

The three dimensions of uncertainty

It is widely recognized that the uncertainty regarding ϕ_t and its relationship to μ_t is enormous (egs., Allen and Frame, 2007; Rosen and Guenther, 2014; Woodward and Bishop, 1997). But there exist two other matters about which it is nearly impossible to be quantitatively precise. In addition to what I call *predictive* uncertainty, we confront *valuational* uncertainty – which is the problem of how to assign monetary values to the uncertain damages (or the uncertain benefits to averting damages) – and *moral* uncertainty – the quandary of how much relative importance to grant future generations of humans.

Only the first of the preceding three categories is generally treated as 'uncertainty' in the economics literature, and with good reason. Allowing too much uncertainty into economic analysis would weaken the claim that economics can be regarded as anything even resembling a precise science. Economists for the most part avoid even mentioning uncertainty; Hodgson (2011) notes that the frequency with which the word has appeared in articles in leading economics journals has been on a steady decline for decades.

Calling attention to valuational and moral uncertainty thus serves two purposes. First, doing so provides a more candid assessment of the limitations of orthodox economic analysis,

[7] While ϕ_t is shown as a function of μ_t, we should expect the two to mutually cause each other. I omitted the reverse link, as well as other likely relationships (including the effect of ϕ_t on α_t) to keep things reasonably simple.

especially when it comes to an issue as critical as climate change. While it has contributed a variety of widely applied concepts and models, there are strong grounds for questioning just how relevant these have been, especially in an environmental context. Controversy on this precise question has resulted in a split between environmental and ecological economics, and then also within ecological economics between those more or less critical of the methodologies that underpin many mainstream approaches.

Second, focusing on valuational and moral uncertainty lays bare the fact that subjectivity in analyzing climate change is inevitable, complicating matters much more than would be evident by focusing exclusively on the complexities of global climate. The more transparent we can be about this, the less temptation there will be to behave as if assigning arbitrary numbers will 'fix' the problem.

3. Predictive uncertainty: Risk, uncertainty, and ignorance

Climate, complexity, and unpredictability

Predictive uncertainty refers specifically to uncertainty about future events. It mostly relates to climate outcomes (ϕ_t), which are in part a consequence of mitigation expenses (μ_t). We do not know what climate change future ($\Phi = \int_{t=0}^{\infty} \phi_t$) awaits us, both because we have insufficient ecological and climatological awareness, and because we do not have adequate information on the response functions that determine μ_t, and α_t. Such uncertainty is not primarily about the market price of mitigation or adaptation technologies, but about the nature of the technologies themselves. Since we do not know what technologies will even be necessary in the future, we know less about how the climate will have responded to our policy action (or lack thereof) the further into the future we look. We cannot, moreover, predict how responsive our collective political will would be to unpredictable future events.

Future climate change outcomes and mitigation and adaptation policy costs are 'positive' issues in the sense that there are no value judgments involved. Despite enormous uncertainty, they are variables for which prediction entails pure, objective analysis. Unfortunately, the absence of value judgments does not make the task of accounting for predictive uncertainty noticeably easier.

Mechanistic models representing a phenomenon that is more or less deterministic often lend themselves nicely to predictive methods. With the aid of computers, today we can identify the relevant differential equations, plug in the known quantitative inputs, and arrive at precise conclusions regarding future outcomes. Yet with the enormous uncertainty and complexity that it entails, climate change is decidedly anything *but* mechanistic. Gowdy (1994), for example, has argued that an evolutionary modeling scheme better characterizes the global climate. While differential equations are usually also appropriate tools for such models, predicted outcomes are often highly sensitive to even minute changes in one or more of the relevant inputs. Uncertainty over details might therefore translate to even greater uncertainty over possible outcomes.

As noted by Weitzman (2009), there are two things we do not know: how much greenhouse gas will be emitted, and what the 'scaling factor' is. Uncertainty over the latter, which is essentially the product of many variables, is far greater.[8] The complex interplay of different factors often gives rise to positive feedback loops. One such case is the melting of planetary ice sheets due to higher global temperatures. We know that since ice reflects solar energy, its widespread melting causes the earth to absorb more solar heat, causing further melting in what is known as ice-albedo feedback. But we do not know *how much* more, nor with what long-term effect. We also have good reason to suspect that increased temperatures will eventually melt sufficient permafrost to release sequestered methane deposits into the atmosphere, again reinforcing the temperature increase. But again, we have almost no idea the magnitude of the effect.

We could say the same about our knowledge of the role of tropical forests and deforestation; we understand the basic relationships but are utterly incapable of accurately forecasting long-term climate effects. Herein lies the fatal weakness of most climate models: while they are very useful and effective and providing insight and explaining phenomena at a basic level, they are unreliable, because of the immense complexity involved, for predicting or forecasting.

Uncertainty and ignorance

Different degrees of predictive uncertainty prevail, and clarifying the differences further illustrates the challenge presented by climate change. For example, a situation of 'weak' uncertainty (Table 1) commonly refers to cases where the outcome is not known *a priori* but all the possibilities and their respective probabilities are.[9] To be sure, for a problem as complex as climate change the assumption of weak uncertainty is wildly unrealistic. Yet in an era in which precise quantitative conclusions are at a premium, it becomes almost compulsory to *assume* weak uncertainty in order to facilitate – or even make possible – certain calculations.

A situation in which all possible outcomes are known but not the probabilities is sometimes misleadingly referred to as *strong uncertainty*. Some (e.g., Woodward and Bishop, 1997) perhaps even more incongruously call it 'pure' uncertainty. Even here we presume that we know all relevant outcomes. Is this more realistic than assuming weak uncertainty? Not in any meaningful way. Since we do not really even remotely know the range of possible climate change outcomes, we are not merely uncertain but largely *ignorant* about the future. It is a distinction often not fully appreciated in quantitative fields like economics.

[8] For example, in addition to the effects of policy on carbon emissions, we are uncertain about the effect of the interplay of these on the accumulation over time of these gases; also about the effect of accumulation on mean global temperatures and the effect of this on regional climates; subsequent policy responses; effects on regional wellbeing; etc.
[9] Davidson (1991) prefers the term 'risk' in order to more easily distinguish it from qualitative uncertainty. Yet while useful for modeling and thought experiments, the notion of weak uncertainty is an example of the 'ludic fallacy,' which refers to the confusion of games or math models with real life. Only probabilities in games can be known a priori. The taxonomy presented in Table 1 is slightly different from Keynes's or Knight's notions of uncertainty, and more like that employed by Dovers and Handmer (1995), who emphasize the distinction between ignorance and uncertainty.

Table 1: Classifying uncertainty and ignorance

	Outcomes	Probability Distributions	Possible Outcomes	Principal need
Certainty	Known	Known	Known	na
Weak uncertainty	Unknown	Known	Known	Outcome
Strong uncertainty	Unknown	Unknown	Known	Probability distribution
Informational ignorance	Unknown	Unknown	Unknown	Greater information on critical inputs
Cognitive ignorance	Unknown	Unknown	Unknown	Improved assimilative capacity
Systemic ignorance	Unknown	Unknown	Unknown	Understanding of complex processes

The three classes of ignorance listed in Table 1 are not mutually exclusive, and indeed all three most likely apply here.[10] Informational ignorance is likely the least of the three problems, and the most surmountable. Arguably, we are already at a point where scientific data that are necessary as inputs into climate models – ocean acidity levels, temperatures, icecap melting rates, etc. – are increasingly available or accessible, thanks to ongoing general improvements in measurement techniques. While there remains much that is still not known, progress in this area is beyond doubt.

More problematic are the other two types of ignorance. Cognitive ignorance refers to the natural limit – cerebral or computational – in our abilities to represent reality through modeling, analysis, and calculation, and to parse seemingly unlimited amounts of data and information. In other words, while human ingenuity and information processing capacity are seemingly without limit, there are some problems so complex as to be intractable even for smart humans and powerful computers. Science is known to present such problems; it is a challenge that neuroscientists, despite (or maybe because of) their recent discoveries, are sure to appreciate. So even *if* we obtained accurate measurements of all the relevant variables, it might not be reasonable to assume, given cognitive ignorance, that even our best models would be able to reveal the 'truth.'

We might therefore say that cognitive ignorance involves 'unknown unknowns,' as opposed to the 'known' unknowns dealt with by informational ignorance. Systemic uncertainty, in contrast, covers what I call *unknowable* unknowns, owing to the extreme complexity involved. This refers to conundrums that are potentially beyond the reach of modern scientific inquiry. While cognitive ignorance could in principle be transcended, systemic ignorance might never be fully overcome. While such an idea is likely to arouse controversy,[11] the paradox of moving further from understanding as we acquire more information is not unheard of in science. Modern-day physicists trying to unify quantum mechanics with Einstein's theory of general relativity no doubt appreciate that the progress they make is anything but linear.

[10] Despite its importance, a fourth type of ignorance – 'willful' ignorance – will not concern us here. This relates to the manipulation of information by some for institutional or political economy purposes in a manner that many others remain ignorant. It is similar to what Davies and McGoey (2012) call 'productive' ignorance.

[11] I recognize that this idea is anathema to most scientists, but it is not necessary to argue the point here. More relevant is whether certain unknowns could become 'knowable' near enough in the future to make a meaningful difference in addressing climate change. Here matters appear more dubious.

4. Valuational uncertainty: Subjectivity, circularity, and threshold effects

Compounding the limitations of quantitative benefit-cost assessments is what I call *valuational* uncertainty. It involves B_t from Equation 1, or the value of the benefits that would result from averting climate change damage. I assume, for the sake of simplicity, that *we know* ϕ_t and τ_t – i.e., that we have perfect foresight about what would befall us as a consequence of any possible combination of mitigation and adaptation strategies. Here we are strictly interested in the potential monetary benefits of such policy.

Even if climate scenario ϕ_t and the corresponding adaptation regime (τ_t) were objectively knowable in principle, the value of B_t would not only be unobservable, it could never be objectively ascertained. Quantitative expression of B_t would require monetary assessment of broad changes in human wellbeing as well as valuation of human lives. Such assessments are inescapably subjective.[12]

Some values, to be sure, involve greater uncertainty than others. However imperfect they might be, markets exist for natural resources like minerals or timber, making the monetary valuation of such resources relatively simple. Furthermore, economists have devised methods such as hedonic pricing or contingent valuation for values relating to the environment for which markets do not exist (e.g., endangered species, aesthetic values).

But valuation becomes intractable in the case of ecosystems contributing multiple benefits. How would we, for example, value the nutrient cycling function of the soil or the carbon sequestration function of our oceans? Absent markets, there are no prices, but insufficient understanding of the interrelated nature of the different ecological functions necessarily makes assessment of their value highly subjective with or without prices. Yet the values cannot be ignored; indeed, ecosystems often possess significant values that at least indirectly impact human livelihoods and lives.

Climate change is a particularly thorny problem because of the vast predictive uncertainty discussed earlier. How can we value the damage resulting, say, from *x* additional parts per million of carbon, when we have a poor understanding of secondary and tertiary effects? Moreover, changes are unlikely to be linear and we presently lack sufficient understanding of the relevant ecological thresholds, beyond which predicting outcomes becomes virtually impossible. In this way, predictive uncertainty becomes intertwined with valuational uncertainty – or the question of what values to assign.

But subjectivity also plays an important role in valuational uncertainty. Since future climate change portends some measure of harm to humans in terms of loss of life and adverse health effects, it seems not only reasonable but also imperative that assessed values reflect these damages. The problem is how this can be ensured. The common orthodox economics argument is that, in our society's customary willingness to undertake risky projects, we

[12] Many believe that it is morally wrong to put dollar values on the natural environment or on the impacts of changes to it on human lives. It is more of an ethical stance than a practical argument, one that opposes relegation of humans or nature to the level of marketable commodities. Detractors insist on assigning monetary values to environmental externalities, ecological benefits, and the like, under the rationale that failure to do so implicitly assigns them values of zero, effectively inviting their eventual degradation or overexploitation. The debate goes beyond our present scope since the principal issue here – the valuational uncertainty involved in monetary assessments of the environment and impacts of changes to it on human lives – is not obviated by its resolution.

'reveal' that we attach some finite value to human life or any harm inflicted upon it (else we would never subject ourselves to any nonzero risk, however infinitesimal). Valuation should then merely be a matter of estimating our 'revealed preference' for human life, through hedonic regression or other conventional techniques, and applying the average estimate to the net benefit function in Equation 1.

Yet before doing so, we should note the circular reasoning in the revealed preference claim. We infer that human life possesses finite value from the fact that we are willing to subject ourselves to some statistical risk in our decisions to build, develop, or otherwise alter the natural environment. As is almost invariably the case with economic analytical models, however, the underlying assumption is that decision makers possess perfect information. In other words, agents are making decisions based on a *known* 'life value.' Effectively, we are assuming that we indirectly know that which we are trying to estimate.

In summary, the challenges to accurately assessing the net monetary benefit of climate change policy are immense. Yet even if we *did* have a reasonable sense of what to expect in the future and a practical means of establishing monetary values, there would remain the question of how to account for the value over time. That is, we would need to address the inescapable tradeoff between the net benefits to present versus future generations. This uncertainty is a question of morality or ethics. To it we now turn.

5. Moral uncertainty: The intractable ethics of discounting

The social discount rate and the Ramsey equation

Let us, for the sake of argument, continue assuming that we have perfect foresight regarding ϕ_t and that, in addition, we possess a means of objectively ascertaining the quantitative value of all the damages averted. In this hypothetical world, it would appear that benefit-cost analysis is all that we would need to determine the optimal mix of climate change policies. Yet if we did not consider the social discount rate – '*d* ' in Equation 1 – we would be disregarding the important question of the value of damages in the present compared to those in the future. The issue is central to the controversy over the Stern Review, mentioned earlier. Researchers were quick to note that its primary policy conclusion – the urgency with which climate change should be addressed – hinges crucially on the chosen social discount rate. I label *moral uncertainty* the ethical challenge of what discount rate to employ for climate change policy.

Discounting is a familiar concept when applied to problems of private savings or investment. The discount rate generally represents the pure rate of time preference (a measure of impatience) in the case of the decision of whether to consume or save; in the case of investment, it typically represents the opportunity cost of capital – i.e., the prevailing rate of return on alternative projects.

But applying discounting to projects producing not only private returns but also positive or negative (environmental or social) externalities immensely complicates matters. 'Payouts' – i.e., benefits and costs – are generally experienced by different parties and at different times. Are these parties equally well off to begin with? (Or will they be?) To what extent does this matter? And to what degree should individuals risk uncertain challenges in the future in return for a greater payoff today? At the core of moral uncertainty is our doubt regarding how much relative importance to accord to future generations.

Some (e.g., Nordhaus, 2007) do not see the problem as too different from a private savings or investment problem, believing that the social discount rate should approximate the private rate of discount. Using the private discount rate for climate change policy *might* make sense if future damage costs were limited to property and other tangible private values as opposed to broader benefits and costs related to human life and wellbeing. But we know that this is not so. Consequently, others (Beckerman and Hepburn, 2007; Broome, 2008) are more circumspect – ambivalent, even – conceding the fundamental ethical nature of the decision. Yet all of the above, and indeed virtually all economists, advocate a positive discount rate in principle.

The dominant belief is that a positive discount rate compensates us for the widespread expectation that future generations will on average be richer than us. But it is not axiomatic that they will be. A high discount rate, in theory, increases the rate of exploitation of the environment and natural resources. Martinez-Alier has noted (1987) that expecting future generations to be richer than us under such circumstances requires assuming an extraordinary elasticity of substitution between the natural environment and whatever might replace it. Also, while we can be optimistic about the advance of scientific knowledge, our optimism does not imply a belief in the discovery of substitutes sufficient to maintain present patterns of consumption in perpetuity, never mind at such a rate to allow for their *growth*, which is what we would infer from a positive social discount rate.

The economic theory behind the social discount rate (d) is generally based on the optimal consumption discount rate suggested in a seminal article by Ramsey (1928), which is based on the tradeoff an economic agent faces between present and future consumption. In the sense in which it shows how to optimize consumption (often taken to be synonymous with wellbeing) over time, his landmark model is suitable for application to the climate change problem. One could argue that it allows us to account for the above concerns, in addition to our expectation regarding the average utility (or income) growth rate into the future. The standard formula for the social discount rate is as follows:

$$d = \delta + \eta g \,, \tag{2}$$

where d represents the social discount rate, δ stands for the utility discount rate – somewhat akin to the pure rate of time preference or index of 'impatience' – η the elasticity of marginal utility with respect to consumption, and g the expected future growth rate of consumption.

Based on Equation 2, part of the justification for a positive discount rate is a δ that is presumably greater than zero. In other words, on average we value the consumption or wellbeing of today's people more highly than that of people in the future. This might be plausible when considering the consumption-savings decision in general, but is dubious when applied to climate change. Here, the possibility of increased 'negative wellbeing' over time (in the form of an expected wellbeing dominated by low probability but extremely high cost catastrophe events) needs to be considered.

Could we, then, justify a positive δ when evaluating climate change net benefits? It is a philosophical matter not taken up here, but suffice it to say that a positive δ is not universally accepted. Broome (2008), for one, argues that we should be 'temporally impartial,' and I am inclined to agree. Regardless, there is no way that the choice between discounting future lives and *not* doing so can be anything but subjective.

Things become more muddled when we get to the ηg product in Equation 2. The problem is that while η is meant to represent the elasticity of marginal utility with respect to consumption, such a characterization is so general as to be misleading. As many (Atkinson *et al*., 2009, and Beckerman and Hepburn, 2007) have noted, the elasticity of marginal utility with respect to consumption should itself be decomposed into three distinct indicators, all highly relevant to the discount rate and climate change in general. These are individual risk aversion (the original consumption-savings problem), society's inequality aversion, and society's aversion to *intergenerational* inequality. So among other problems, we have the issue of one of the formula's parameters serving three functions.[13]

As for the expected average growth rate (g), including it as a component of the social discount rate is potentially self-countervailing. True, the assumption that future economic growth will be positive and that future people will therefore be better off than us should call for a positive discount rate. But the potential consequence of a positive rate, especially a very high one – that we stop looking after the needs of future people – undermines the original assumption. If, in other words, we are short sighted today, there will likely be less productive capital available for future use (leading to slower growth).

The ethics of climate change discounting

Ethics aside, then, the social discount rate is fraught with methodological weaknesses. Does this mean we should dispense with it as a policy tool? Beckerman and Hepburn (2007) are among those supporting the use of Ramsey's formulation, despite its faults. They argue that it provides a means of avoiding the two extremes of marketplace 'revealed ethics' – where the social discount rate is inferred from market behavior in relation to private investments – and the dictates of 'philosopher kings' who purport to have some particular expertise and because of this should be entrusted with a potentially momentous decision that could be made arbitrarily.

Broome (2008), in contrast, maintains that reliance on professional expertise is not inconsistent with democracy, as long as the discount rate established by the experts is merely one of many inputs into the (democratic) policymaking process, as opposed to itself being an output computed from shaky inputs based on questionable assumptions and ethical stances. He nevertheless appears to have no issue with expressing our social preference for future generations as a precise figure.

His is a questionable stance, given the inescapable methodological and ethical issues involved. In an article describing secular attitudinal changes in the United States, Oberhoffer (1989) claims that our 'cultural discount rate' has increased over time. Yet he uses the term metaphorically to support his claim that Americans today place less importance on posterity

[13] These authors, among others, have noted the potentially contradictory nature of allowing η to simultaneously reflect these three policy-relevant concepts. A relatively high η, for example, implies greater risk aversion, calling for more aggressive climate change policy. Yet at the same time it reduces the weight of future consumption relative to the present, implying *less* aggressive policy. Atkinson *et al*. (2009) find weak grounds for combining the three concepts into one indicator, and conclude that they should instead be disentangled and represented as three separate variables.

than we once did, nowhere seeking to express it numerically. Oberhoffer appears to appreciate the dangerous seductiveness of a precise figure as a substitute for critical judgment and, to his credit, rejects it.

Broome should adopt a similar tack in the case of climate change. Discounting makes eminent sense for financial investments, but in the social arena it is a misguided attempt to quantify and thereby objectify what is a fundamentally ethical and therefore qualitative problem.[14] Its use is inappropriate for a problem as urgent and momentous as climate change.

There is, in short, no objective basis for ascertaining a 'correct' discount rate on which to base future climate change. Many social benefit-cost studies elide the question of the appropriate discount rate, simply assuming one and burying this detail in otherwise ostensibly objective results. For a high stakes problem like climate change, the enormous moral uncertainty that we have seen is further unambiguous grounds for rejecting social benefit-cost analysis as a policy tool. All three types of uncertainty – predictive, valuational, and moral – argue for extreme caution in drawing conclusions from figures that are based on imperfect understanding of the multidimensional challenge that is climate change.

6. Conclusion

Climate change is a truly interdisciplinary problem, not only involving atmospheric sciences, but also economics, ecology, philosophy, and ethics. The different disciplines introduce different layers of climate change uncertainty; here I have focused on three. *Predictive* uncertainty refers to the difficulty, owing to the extreme complexity of the global climate and attendant feedback effects, in achieving any degree of precision in anticipating future outcomes. *Valuational* uncertainty refers to the impossibility – both because of links to the previous and because of inherent subjectivity – of assigning monetary values to the future damages or to the benefits of preventing them. Finally, *moral* uncertainty refers to the irresolvable matter of how much relative importance to place on the wellbeing of future generations of people.

Given these three forms of uncertainty, it would seem reckless to insist on quantitative precision as a condition for undertaking ameliorative policy. Make no mistake: the extreme caution that we should observe in drawing conclusions from precise figures on highly uncertain matters does not translate to extreme caution in climate change policy. Not knowing the precise costs and benefits is hardly reason to dither, especially since it is well established that climate change is real. Woodward and Bishop (1997) correctly argue that a policy stance that assumes the worst is the most robust to alternative future scenarios.

It brings to mind the precautionary principle, whereby the burden of proof is on agents who would irreversibly – and potentially adversely – alter the natural environment through economic activity. Principle 15 of the 1992 Rio Declaration (UNCED, 1992) states:

> In order to protect the environment, the precautionary principle shall be widely applied by the States [UN members] according to their capabilities.

[14] For far more elaboration on this point, see Best (2012), Schumacher (1973), and Torras and Surie (2016).

> Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.

While the precautionary principle is usually invoked in reference to a specific project, such thinking is overdue for more encompassing global problems such as climate change.

Social benefit-cost analysis is unreliable as a guide to how aggressively we should address climate change; but it is almost as unreliable in helping us decide upon an appropriate mix of mitigation and adaptation policies. One of the more under remarked realities we confront is that it *might be too late* for mitigation to offer significant hope and that it might make more sense to direct our resources at adaptation and survival. Whether or not this is true depends, of course, on the extent of existential risk that our species faces. We are presently deeply uncertain about this, and it is a subject sure to inspire much future research.

The foregoing discussion hints at two other potential research streams. The first is the possible elaboration of a new paradigm for economic analysis that extends beyond the narrow notion of predictive uncertainty (including its exceedingly narrow treatment even of this) and dispenses with the mathematically convenient assumption of perfect information and foresight. As a policy science, economics must recognize that it is both impossible and undesirable to purge uncertainty, and the subjectivity that often relates to it, from most evaluative contexts. Any future challenge to the dominance of neoclassical economics would do well to consider this.

Second, and following from this, is a greater exploration of policy approaches that more evenly balance quantitative and qualitative concerns. Economists traditionally rely on forecasting, which seeks to reduce all relevant phenomena to numbers in order to more precisely 'predict' the future. If nothing else, the foregoing discussion suggests that a matter as complex as climate change calls for a more 'humble' policy that concedes lack of precision and instead considers scenarios or ranges of possible outcomes. When dealing with a situation with a nonzero probability of catastrophic effects on humans, it is preferable to satisfice based on expert judgment on what we know and what we do not than to seek to optimize based on information that is precise but most likely wrong.

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