WHAT WE KNOW AND DON'T KNOW ABOUT CLIMATE CHANGE, AND IMPLICATIONS FOR POLICY*

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INTRODUCTION ONLY (EXTENDED ABSTRACT)

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1 Introduction.

There is a lot we know about climate change, but there is also a lot we don't know. Even if we knew exactly how much CO_2 and other greenhouse gases (GHGs) the world will emit over the coming decades, we wouldn't be able to predict (with any reasonably precision) how much the global mean temperature will rise as a result. Nor would we be able to predict other aspects of climate change, such as rises in sea levels, an increase in the frequency and intensity of storms, hurricanes and droughts. And even if we were able to predict the extent of climate change that will occur over the coming decades, we can say very little about its likely *impact* — which in the end is what matters. The fact is that we face considerable uncertainty over climate change, and as we'll see, that uncertainty has crucial implications for policy.

Despite the uncertainty, the debate over climate policy is usually framed in deterministic terms. We start with some scenario regarding GHG emissions, perhaps under "business as usual" (BAU) or under some emission abatement policy, and then make and discuss projections of temperature change through the end of the century. Sometimes those projections include high, medium, and low alternatives, but without much basis for how and why those alternatives differ as they do. We then talk in broad and often vague terms about the likely impacts of those temperature changes — reductions in agricultural output, reduced productivity generally, greater damage from more intense storms and droughts, and perhaps displacements of populations if rising sea levels inundate low-lying areas. We sometimes try to translate those impacts into percentage reductions in GDP, which is necessary if we want to come up with a number for the social cost of carbon (SCC). We know that those impacts are very difficult — perhaps impossible — to predict because climate change happens slowly, over decades, and we don't know the extent of adaptation that will occur in response.

And despite all the uncertainty, we evaluate climate change policies in terms that suggest a high level of precision is possible. As I have argued elsewhere, this is particularly true when we use complex integrated assessment models (IAMs) to make outcome and impact projections, evaluate alternative policies, and estimate the SCC.[1] But as I will argue, it is the uncertainty over climate change and its impact that is critical to policy formulation, and that should be the focus of analysis and discussion.

To get a sense of why the uncertainties are so important, consider the irreversibilities

[1] For a discussion of the flaws in IAMs that make them unsuitable for policy analysis, see Pindyck (2013*b*,*a*, 2017). The U.S. Government's Interagency Working Group (IWG) used three IAMs to estimate the SCC; see Interagency Working Group on Social Cost of Carbon (2013), and for a discussion of the Working Group's methodology and the models it used, see Greenstone, Kopits and Wolverton (2013).

that are an inherent part of climate policy (and environmental policy more generally). It has been long understood that environmental damage can be irreversible, which can lead to a more "conservationist" policy than would be optimal otherwise. Thanks to Joni Mitchell, even non-economists know that if we "pave paradise and put up a parking lot," paradise may be gone forever. And if the value of paradise to future generations is uncertain, the benefit from protecting it today should include an option value, which pushes the cost-benefit calculation towards protection. But there is a second kind of irreversibility that works in the opposite direction: Protecting paradise imposes sunk costs on society. If paradise is clean air and water, protecting it could imply sunk cost investments in abatement equipment, and an ongoing flow of sunk costs for more expensive production processes. This kind of irreversibility would lead to policies that are *less* "conservationist" than they would be otherwise.

Which of these two irreversibilities applies to climate policy? Both. Given that they work in opposite directions, which one is more important? We don't know.[2] Because CO_2 can remain in the atmosphere for centuries, and ecosystem destruction from climate change can be permanent, there is clearly an argument for taking early action. But the costs of reducing CO_2 emissions are largely sunk, which implies an argument for waiting.[3] Which type of irreversibility will dominate depends in part on the nature and extent of the uncertainties involved, and will be explored in this paper.

There is another reason why the uncertainties over climate change are so important, and it has to do with "tail risk." If climate change turns out to be moderate, and its impact turns out to be moderate, we may not have too much to worry about. But what if climate change and its impact turn out to be catastrophic — the far right tail of the outcome distribution. It is that possibility, even if the probability is low, that might drive us to quickly adopt a stringent emission abatement policy. In effect, by reducing emissions now we would be buying insurance. But how much of a premium should we be willing to pay for such insurance? The answer depends in part on society's degree of risk aversion, which is complex and hard to evaluate. As I will show, however, the risk premium could be considerable.

This paper has two main parts. First, I lay out what we know, don't know, and sort of know about climate change, and discuss *why* we don't know certain things, and the nature

[2]A number of studies have explored this question in a theoretical setting; see, e.g., Kolstad (1996), Ulph and Ulph (1997), and Pindyck (2000). These studies illustrate the fundamental problem, but don't tell us how to formulate climate policy.

[3]There are other arguments for waiting or starting slowly: technological change may reduce abatement costs in the future, and the fact that the "unpolluted" atmosphere is an exhaustible resource implies that the SCC should rise over time (as the atmospheric CO_2 concentration rises).

of the uncertainties. One of the two more important uncertainties pertains to the extent of warming (and other aspects of climate change) that will occur given current and expected future GHG emissions. The second uncertainty pertains to the economic impact of any climate change that might occur, an impact that depends critically on the possibility of adaptation. We simply don't know how much warmer the world will become by the end of the century under the Paris Agreement, or under any other agreement. Nor do we know how much worse off we will be if the global mean temperature increases by 2°C or even 5°C.

In fact, we may never be able to resolve these uncertainties (at least over the few decades). It may be that the extent of warming and its impact are not just unknown, but also unknowable — what King (2016) refers to as "radical uncertainty," or extreme Knightian uncertainty.[4] And as King (2016) puts it (in a very different context), "The fundamental point about radical uncertainty is that if we don't know what the future might hold, we don't know, and there is no point pretending otherwise."[5] But even though we may never resolved these uncertainties, we *can* characterize them and better understand them.

That leads to the second part of this paper, which deals with the *implications of uncertainty* for climate policy. In a risk-neutral world with no irreversibilities, only the expected values of outcomes should matter, not the degree of uncertainty over those outcomes. But macroeconomic and financial market data suggest that society (or at least the people that make up society) is far from risk-neutral, so that there is likely to be a significant insurance value to reducing GHG emissions now. Likewise, we know that there are two types of irreversibilities at play, which work in opposite directions. In formulating climate policy, what is the insurance value of GHG emission reductions, and what is the net effect of the relevant irreversibilities? This paper addresses those questions.

In the next section, I lay out the steps through which emissions of CO_2 (and other GHGs) accumulate in the atmosphere, increases in the atmospheric CO_2 concentration affect the global mean temperature (and regional temperatures), how temperature increases affect sea levels as well as other aspects of climate, and how changes in climate can in turn have economic and social impacts (i.e., "damages"). I'll characterize in general terms the state of our knowledge with respect to each of these steps, i.e., the extent of our uncertainty. For two of these steps — how rising GHG concentrations affect climate, and how climate change causes damages — the uncertainty is huge.

Next, I will refine the statement that "the uncertainty is huge." I will try to characterize

[4]For explanations of why "radical uncertainty" is likely to apply to climate change, see, e.g., Allen and Frame (2007) and Roe and Baker (2007).

[5]I would argue that the IAMs and related models used for policy analysis pretend otherwise.

these uncertainties in terms of probability distributions that can be roughly supported by existing studies in climate science and economics. I will address the question of whether those distributions have "fat tails" (and whether that even matters). I will also review the evidence on how these uncertainties are changing over time. (As I will explain, between the 2007 and 2014 IPCC reports, uncertainty over how changes in the atmospheric CO_2 concentration affect temperature has actually *increased*.) This is important because it addresses the value of waiting for new information rather than taking immediate action now.

I will then turn to the implications of uncertainty for policy. First, how does climate change uncertainty interact with the two opposing irreversibilities outlined above? I will address this question using a simple two-period model calibrated to data from Intergovernmental Panel on Climate Change (2014) and other sources. Second, how does climate change uncertainty create an insurance value of early action, and can we get a rough idea of how large that insurance value is? I will address this question in part using "willingness to pay" (WTP) estimates, along the lines of those in Pindyck (2011, 2012).

Outline of Paper.

What We Know and Don't Know. The basic mechanism behind climate change. The concept of equilibrium climate sensitivity (and transient climate sensitivity). Equilibrium climate sensitivity is a useful "summary statistic," but it is highly uncertain. The nature of climate impacts: temperature (global and regional, air versus ocean), sea levels, hurricanes, etc. Why it is so difficult to estimate the impacts.

Characteristics of Uncertainty over Climate Sensitivity. Probability distributions for climate sensitivity. Many, many studies are available, so why is the uncertainty so large? Histograms of "most likely," high and low estimates from about 50 studies done over the last 20 years. A critical problem: the role of feedback loops. What is the best distribution: Displaced gamma? Lognormal? Do fat or thin tails matter? (No.)

Characteristics of Uncertainty over Impacts. Discussion of uncertainty over different potential impacts of climate change, summarized in the form of reduced GDP (level or growth rate). How to characterize the uncertainty, and the limits to what we can and cannot say about impacts.

Policy implications of Irreversibilities. A simple two-period model calibrated to data from IPCC and other sources. What does it tell us?

Insurance Value and its Implications for Policy. Can we roughly estimate the insurance value of early action, at least for alternative assumptions regarding social risk

aversion? I will address this question in part using "willingness to pay" (WTP) estimates like those in Pindyck (2012).

Conclusions. Summary of basic points, and caveats. Where more work is needed. Implications for policy.

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