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## High unknowability of climate damage valuation means the social cost of carbon will always be disputed

CCEP Working Paper 1802

January 2018

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### **Abstract**

The social cost of carbon (SCC), a carbon price calculated from cost-benefit based integrated assessment models and used to inform some climate policies, will always be highly disputed, partly because a key model assumption, the centennial climate damage valuation function (CDF), will "always" be highly unknowable. Current disputes are highlighted here by the huge range of SCCs resulting from alternative values of key parameters like discount rates, climate sensitivity and the CDF; by the implausibility to climate scientists of a leading model's warming projections; and by strong criticisms of mainstream CDFs by many climate economists. The claim that statistical analyses of "weather" impacts on local economies can improve centennial CDFs rests on untestable out-of-sample extrapolation. Compared to astronomy, geology and other earth sciences, prediction testing in climate science is generally harder because of Earth's uniqueness, and the unprecedented range and speed of likely centennial climate change, but stable underlying laws make modelling based on past observations meaningful. By contrast, the added complexity of human behaviour means there are no reliable laws for modelling centennial CDFs. For this reason alone, SCCs will always be disputed. I suggest instead more use of carbon prices based on marginal abatement costs, computed on cost-effective paths that achieve socially agreed, physical climate targets. Downplaying the SCC approach to carbon prices poses challenges to many economists, and a cost-effectiveness approach is no panacea, but it avoids the illusion of optimality, and allows more detailed analysis of many current climate policies.

**Key words:**

Climate policy; cost-benefit analysis; global warming; centennial damage valuation; high unknowability; cost-effectiveness analysis

**JEL codes:**

Q54, Q51, D80, D61, E17, C18

**Suggested Citation:**

Pezzey, J. C. V. (2018), High unknowability of climate damage valuation means the social cost of carbon will always be disputed. CCEP Working Paper 1802, January 2018. Crawford School of Public Policy, The Australian National University.

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# High unknowability of climate damage valuation means the social cost of carbon will always be disputed

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7 December 2017

**Abstract.** The social cost of carbon (SCC), a carbon price calculated from cost-benefit based integrated assessment models and used to inform some climate policies, will always be highly disputed, partly because a key model assumption, the centennial climate damage valuation function (CDF), will "always" be highly unknowable. Current disputes are highlighted here by the huge range of SCCs resulting from alternative values of key parameters like discount rates, climate sensitivity and the CDF; by the implausibility to climate scientists of a leading model's warming projections; and by strong criticisms of mainstream CDFs by many climate economists. The claim that statistical analyses of "weather" impacts on local economies can improve centennial CDFs rests on untestable out-of-sample extrapolation. Compared to astronomy, geology and other earth sciences, prediction testing in climate science is generally harder because of Earth's uniqueness, and the unprecedented range and speed of likely centennial climate change, but stable underlying laws make modelling based on past observations meaningful. By contrast, the added complexity of human behaviour means there are no reliable laws for modelling centennial CDFs. For this reason alone, SCCs will always be disputed. I suggest instead more use of carbon prices based on marginal abatement costs, computed on cost-effective paths that achieve socially agreed, physical climate targets. Downplaying the SCC approach to carbon prices poses challenges to many economists, and a cost-effectiveness approach is no panacea, but it avoids the illusion of optimality, and allows more detailed analysis of many current climate policies.

Conflict of interest: The author has declared no conflicts of interest for this article.

## INTRODUCTION

The social cost of carbon (SCC) is the damage to social welfare, aggregated globally and discounted over a century or more into the future because of the atmospheric lifetime of CO<sub>2</sub> (Archer et al. 2009), that is caused by an extra tonne of CO<sub>2</sub>-equivalent emissions in a given year. SCCs are estimated by a subset of Integrated Assessment Models (IAMs) which effectively do cost-benefit analyses (CBAs) of the global climate-economy's future, using dozens of assumptions, many of them highly uncertain (Beck and Krueger 2016). SCCs are used as carbon prices to satisfy some government requirements for CBA of climate policies and other regulations (e.g. Pizer 2017). This article gives one key reason why, provided a *centennial* time horizon is considered, deep disputes about the SCC will endure "always", meaning for many decades to come. Governments can obtain consensus SCC estimates from chosen committees of economists (e.g. IWG 2010, 2016), but I contend that academic SCC estimates made in say, 2050, will still disagree vastly, as they have done since at least the fierce IPCC debate in 1995-6 (Grubb et al. 2014, pp.24-5). Indeed, if I am right, there will be no formal need to take up *WIREs Climate Change's* invitation to update this article 3-5 years from now, as its basic conclusions will remain valid for decades.

Among many IAM assumptions, four key ones are about discount rates; climate sensitivity, the equilibrium global warming from a doubling of atmospheric CO<sub>2</sub>; the climate damage (valuation) function (CDF), usually defined as the proportion of global GDP lost as a function of the warming level; and regional welfare weightings. Below I show how disputes about the first three assumptions can result in hundreds-fold variations in current SCC estimates, a range noted by IPCC (2014, Box 3.1). But as my main focus, I choose to highlight only why extreme difficulties in estimating CDFs for "high" global warming – here more than about 3°C, which could be reached by 2100 under many scenarios (IPCC 2014, Fig. SPM.5) – will endure for decades, to the extent that CDFs should be regarded as "highly unknowable". (A similar but not identical term is "irreducibly uncertain" (Funtowicz and Ravetz 1993).) For this reason alone – though disputes over discounting and regional weighting are two further reasons (Grubb et al. 2014, pp.24-27) – no scientific consensus on SCCs can "ever" be reached, and alternatives to using SCCs in climate policies should be considered.

Many of my arguments are similar to Pindyck's (2013, 2017), but with two key differences. First, I consider fundamental problems in scientific methodology which explain *why* CDFs are so durably uncertain. Second, my suggested alternative to IAM-based SCCs differs from Pindyck's 2017 idea (p.102) of using "expert opinion to determine the inputs to a simple...model" that calculates an SCC. Instead I join many others, like Ackerman and Finlayson (2006), Dietz and Fankhauser (2010), van den Bergh and Botzen (2015), and notably the High-Level Commission on Carbon Prices (CPLC 2017), in suggesting

downplaying or in some cases abandoning SCCs, and instead making greater use of carbon prices, computed using different IAMs with no CDFs, on cost-effective abatement pathways that achieve socially agreed physical climate targets like maximum global warming (UN 2009, 2015).

I start by illustrating how alternative assumptions used by leading climate economists for two discount rate parameters, climate sensitivity and the CDF can yield such wide-ranging SCC estimates. Then follow examples of why climate scientists find mainstream IAM projections implausible, of economists' criticisms of mainstream CDFs, and discussion of the real, but limited, prospects for improving CDFs using statistical analyses of past "weather" impacts on economic outcomes.

The next section gives examples of how predictions in non-experimental sciences like astronomy and geology can be tested, though usually not controllably, using comparators. By contrast, climate science and economics deal with the unique, centennial future of the Earth's vastly complex climate-economy system. And whereas there are agreed, stable laws underlying the climate system's evolution, which support the testing of climate science models against past data, the lack of such laws underlying centennial, human responses to climate change makes CDFs, and SCCs based on them, "highly unknowable".

I then discuss the aforementioned alternative to CBAs and SCCs: much greater use of cost-effectiveness analyses (CEAs). The marginal abatement cost (MACs) from these can be a basis for carbon prices to guide detailed climate policies and other regulations, including prices for individual regions or sectors which are unobtainable from an SCC approach. Nevertheless, CEAs are no panacea. They face the same uncertainties as CBAs over long-term abatement costs and climate sensitivity, and downplaying CBAs of climate policies raises discomfiting political, professional and psychological challenges for many economists.

## **THE SOCIAL COST OF CARBON: UNRESOLVABLE OR IMPROVABLE?**

### **Some key IAM parameters, and the huge range of resulting SCC estimates**

A typical IAM contains dozens of exogenous parameters, some scientific and others economic and/or ethical, which substantially influence the model's estimation of a time series of SCCs. [Table 1](#) shows some effects on the SCC in 2015 of alternative, disputed values of four key parameters in DICE, a "a global model that aggregates different countries into a single level of output, capital stock, technology, and emissions" (Nordhaus 2008; see Nordhaus 2017 for details of the current, 2016R version), one of three leading IAMs used by the US government in IWG (2016).

**TABLE 1: Hundreds-fold range of SCCs from alternative assumptions used with DICE-2016R**

<i>Selected parameters and changes to parameters in the DICE-2016R Integrated Assessment Model (Nordhaus 2017)</i>	<i>Optimal social cost of carbon (SCC) in 2015 (2010 USD/tCO<sub>2</sub>)</i>		
DICE-2016R standard: social time preference, $\rho = 1.5\%/yr$ ; consumption elasticity <sup>1</sup> $\eta = 1.45$ ; climate sensitivity = $3.1^\circ C$ ; climate damage function, $CDF = D(T)/[1+D(T)]$ where $D(T) = 0.00236T^2$ from $T^\circ C$ global warming	29 <sup>2</sup>		
Lower discounting as in Stern (2007): time preference $\rho = 0.1\%/yr$ , consumption elasticity $\eta = 1$	263	456	5929
Higher climate sensitivity = $4.5^\circ C$	44		
Higher climate damage: $D(T) = 0.00239T^2 + 0.0000825T^{6.754}$ (Dietz & Stern 2015's High Damage function)	156		

As shown, the changes to time preference and consumption elasticity proposed by Stern (2007) together improve intergenerational equity by lowering the real dollar discount rate – though their "prescriptive" idealism has been criticised (Nordhaus 2007) – and raise the SCC about 9-fold to \$263/tCO<sub>2</sub>. Also raising climate sensitivity to 4.5°C, the upper limit of its "likely" range in IPCC (2014), nearly doubles the SCC again to \$456/tCO<sub>2</sub>. Assuming Dietz and Stern's (2015) High Damage function, which assumes 50% GDP loss at 4°C warming, in place of DICE's damage function on its own raises SCC more than 5-fold to \$156/tCO<sub>2</sub>, but in combination with lower discounting and higher climate sensitivity it raises SCC further to \$5929/tCO<sub>2</sub>, 200 times DICE's standard estimate.

DICE has about 50 other exogenous parameters, many of which also strongly affect the SCC, especially the assumed rate of Total Factor Productivity growth (Andersen et al. 2014, Millner and McDermott 2016). One highly sensitive IAM parameter group not in DICE, because it is a globally averaged model, is different equity weightings for world regions; see for example Anthoff and Tol (2013). Ethical and political disputes about discount rates and regional weights alone (i.e. aggregation over time and space) may prevent consensus ever being reached on the SCC (Grubb et al. 2014, pp.24-27); but as noted, my chosen focus here is on the CDF. I now highlight three main problems with it: the implausibility to climate scientists of leading IAMs' CDFs (illustrated next for DICE); wide-ranging criticisms by many economists of the arbitrary guesses found in all CDFs for

<sup>1</sup> The rate at which benefit from extra consumption declines as people get richer. Higher time preference and/or higher elasticity results in higher discounting of future benefits and costs.

<sup>2</sup> The damage function code in DICE2016R,  $D(T)$ , nonsensically exceeds 100% for high enough warming. So  $D(T)$  has been replaced here by  $D(T)/[1+D(T)]$ , as in Nordhaus (2008); hence this lower standard SCC than the \$31/tCO<sub>2</sub> reported in Nordhaus (2017).

high warming; and the impossibility, I will argue, of "ever" reaching even a rough scientific consensus on a centennial CDF.

### **The implausibility to climate scientists of a leading IAM's projections**

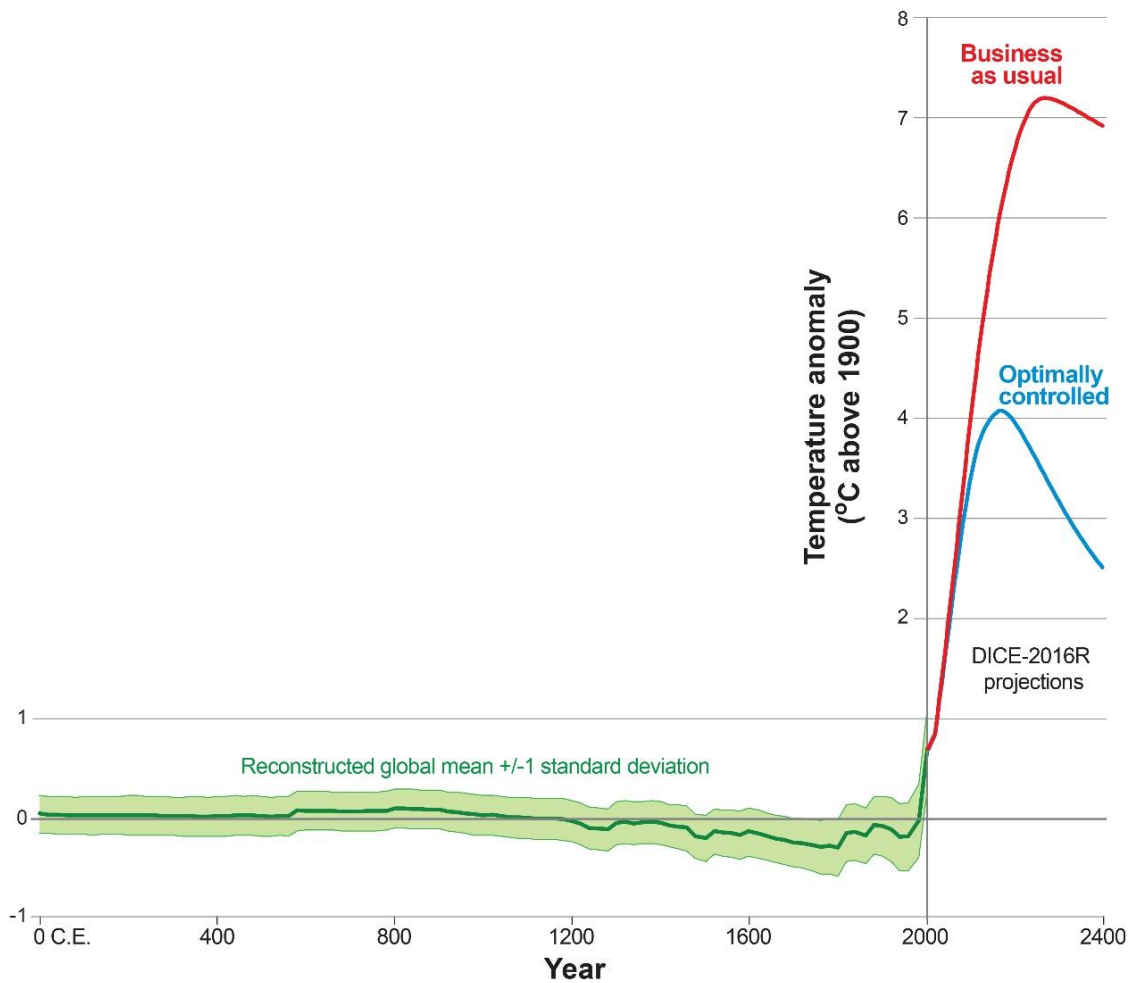
Figures 1 and 2 illustrate the first problem. Global mean temperature stayed within about a 1°C-wide band for the last 11,000 years (Marcott et al. 2013, Fig. 1), the Holocene period in which all human settlements have developed. Figure 1 shows the last 2,000 years, so as to display DICE's projections to 2400 clearly. The projected peak of "optimally controlled" global warming of 4.1°C in 2165 would be unprecedented, by exceeding any levels seen regularly for at least 10 million years, while peak warming of 7.2°C in 2270 on DICE's "Business-as-usual" path, which entails minimal emissions control, would exceed levels seen for about 40 million years (Zachos et al. 2008).

Warming rates, past and future, are also dramatically unprecedented. The 1.7°C/century rise during 1970-2015 (NOAA 2016) was about 170 times the baseline cooling rate since 5000 BCE (Steffen et al. 2016), while DICE's projected optimal warming in Figure 1 of 2.9°C from 2015 to 2115 would be 290 times. A key reason why DICE projects such unprecedentedly high, fast warming to be optimal is its CDF,  $D(T)$  in Table 1, which assumes only 4% and 11% damage to global GDP from 4.1°C and 7.2°C warming respectively. This small difference in damage is the main reason why the drop in projected growth during 2015-2400 of consumption per person net of climate damage (DICE's measure of average well-being) in Figure 2 is so small, from 53-fold growth on the optimal path to 40-fold growth on the Business-as-usual path.

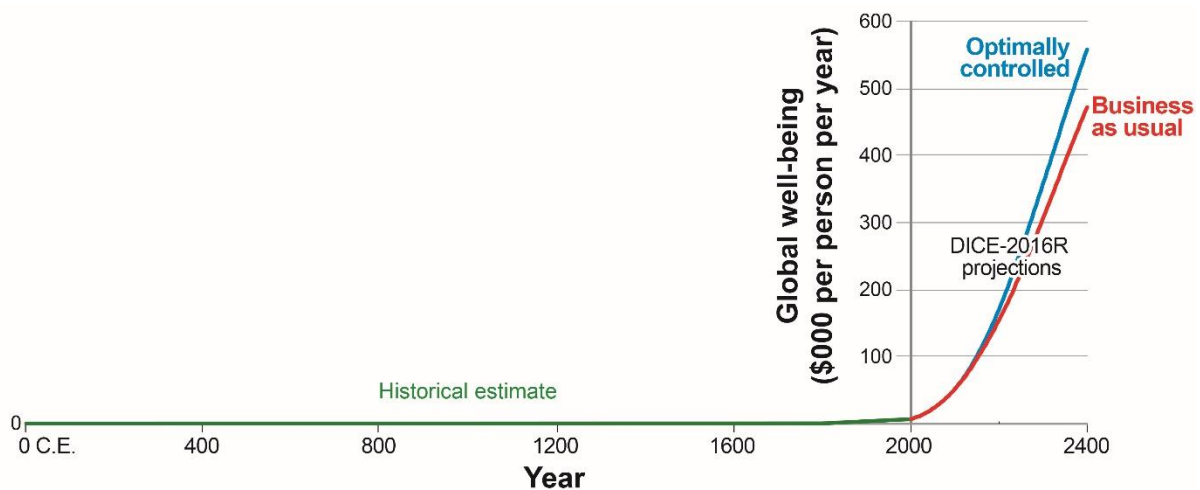
When shown such projections, climate scientists typically express disbelief, derision or dismay that a 2.9°C/century approach to 4.1°C peak warming could ever be regarded as "optimal". As befits their discipline, though, their published warnings about damage from high, fast warming are usually expressions of grave planetary concerns – for example, that "projected warming will...reshape the geography and ecology of the world" (Clark et al. 2016) – rather than direct criticisms of CDFs or IAMs incompatible with such concerns.

### **Economists' criticisms of IAMs' climate damage functions**

By contrast, a significant minority of climate economists do criticise the CDFs used by leading IAMs for severely underestimating climate damage. For example, Stern (2013, pp.840-1) implicitly rejected 4°C warming being "optimal", by quoting the above 10-



**FIGURE 1:** Reconstructed global mean temperature anomalies for 0-2015 CE (from Marcott et al. 2013, Figure 1C), and DICE-2016R projections for 2015-2400 (author's calculation)



**FIGURE 2:** Global well-being measures: GDP/person estimates for 0-2000 (from Maddison 2007), and DICE-2016R projections of per-person consumption net of climate damage for 2015-2400 (author's calculation)



million-year novelty and unprecedented speed of such warming, and suggesting a resulting "risk of vast movements of population" that "history indicates...could involve severe, widespread and extended conflict". Many writers, including leading IAM authors themselves, have noted the many types of damage, like biodiversity loss and ocean acidification, omitted from or understated in such IAMs' CDFs (Nordhaus 2013, pp.10-11; Stern 2013, p.842). Many writers (e.g. Ackerman et al. 2010, Weitzman 2012, Pindyck 2017) criticise the dominant quadratic form of  $D(T)$  as lacking evidence, particularly for high warming. This matters for climate policy, since persistent uncertainties, notably in climate sensitivity (Freeman et al. 2015), mean that even with stringent global abatement that might have limited global warming this century to 2°C, there is a substantial risk of warming above 3°C (IPCC 2014, Table 3.1). As alternatives, modellers critical of the leading IAMs (e.g. Ackerman et al. 2010, Weitzman 2012, Dietz and Stern 2015, Lontzek et al. 2015 and Cai et al. 2016) have tried any or all of: much higher exponents on  $T$ ; making various parameters stochastic, sometimes with jumps to represent tipping elements in the climate; and assuming that warming harms the capital stock or Total Factor Productivity as well as current GDP. Such variety emphasises the deep uncertainties about CDFs.

This last assumption challenges the near-exogeneity of GDP growth rates in mainstream IAMs like DICE, in which "future generations are more or less assumed to be better off" (Stern 2013, p.849 and Table 1), as in Figure 2. But the assumption faces a similar problem to that facing the growing use of stochastic parameters in IAMs – namely, "we don't know the correct probability distributions that should be applied to various parameters" (Pindyck 2017, p.103) – for how can one test the centennial damage done by climate change to capital or Total Factor Productivity? I contend – though others dispute, as noted below – that in the CDF(s) used in *any* IAM-based SCC estimate, one can find (though sometimes only by diligent searching) some arbitrary guesses unfounded on empirical evidence. [Box 1](#) gives a date-ordered selection of recent quotations supporting this contention, some of which go further and conclude that CDFs are to some extent "unknowable". My preferred term is "highly unknowable", since few would disagree that 4°C warming causes more than 0.1% GDP damage, but such weak lower bounds are no use to policymakers. However, any "unknowability" of CDFs is strongly contradicted by many influential writers, as discussed next.

### **Can statistical research improve climate damage function estimates?**

A dominant view among leading climate policy researchers is that much more research is needed to, and will, improve estimates of SCCs (e.g. Revesz et al. 2014, Dell et al. 2014, Sterner 2015, Burke et al. 2016, Pizer 2017 and Diaz and Moore 2017). Some

### **BOX 1. Quotations on guesswork and unknowability in climate damage functions**

Ackerman et al. (2010, p.1662). "There is essentially no relevant empirical research, and it is not clear whether there ever could be any, except after the fact. Our assumed distribution [for the damage function exponent] was selected purely for comparability with guesses made by other analysts."

Weitzman (2012, p.234). "...neither I nor anyone else has an objective basis for determining magnitudes of high-temperature damages."

Pindyck (2013, pp.869-870). "It is difficult to see how our knowledge of the economic impact of rising temperatures is likely to improve in the coming years. More than temperature change itself, economic impact may be in the realm of the 'unknowable'. ... IAM damage functions are completely made up, with no theoretical or empirical foundation."

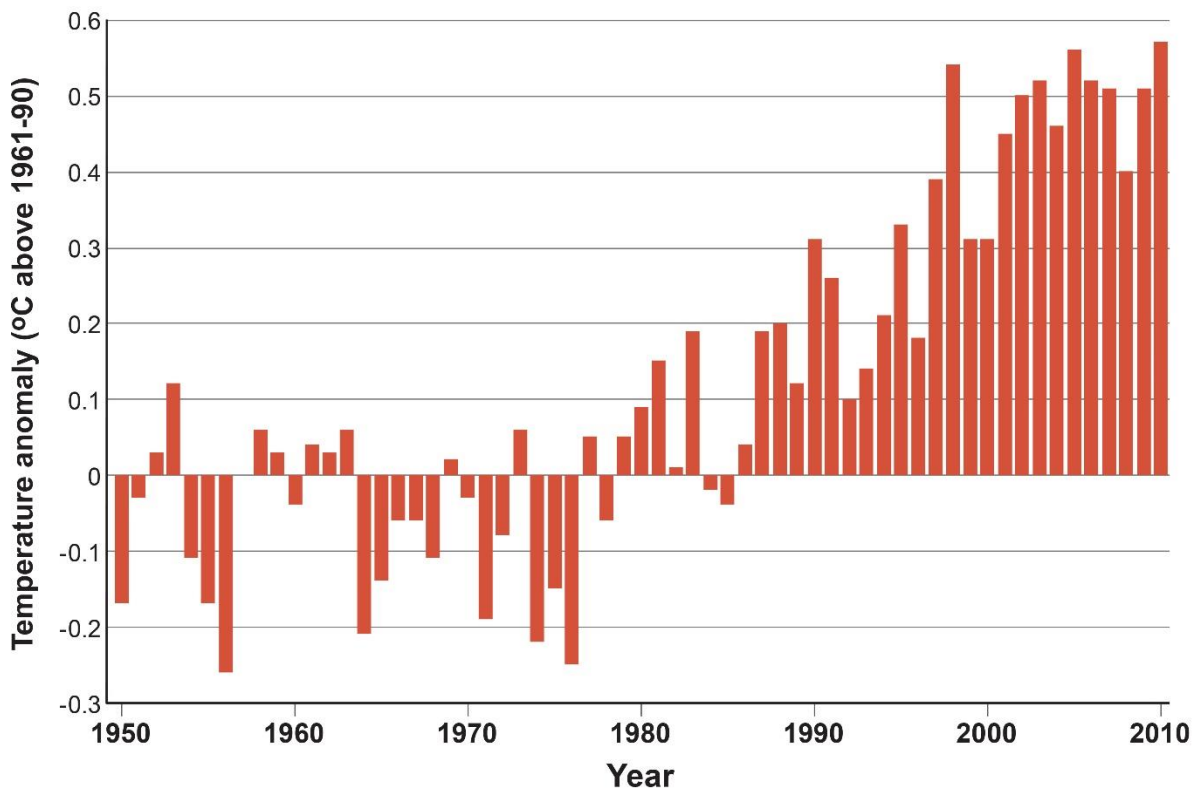
Pezzey and Burke (2014, p.143). "...future climate damage is, and will very probably remain, unknowable to a high enough degree to justify valuing CO<sub>2</sub> emissions inductively..."

Convery and Wagner (2015, p.313). "Some aspects of climate change are simply unknowable, at the very least in the timescales necessary to be able to act and influence long-term climate outcomes."

authors are confident that the resulting SCCs can only be higher, while others are more agnostic; but they all highlight what Dell et al. (2014) called the New Climate-Economy Literature (NCEL). This uses advanced statistical analyses and meta-analyses of the impacts of high-frequency (e.g. annual or monthly), sub-global (e.g. state- or county-level), "weather" fluctuations on a wide range of economic variables. Notable recent contributions by Burke et al. (2015b), Carleton and Hsiang (2016) and Hsiang et al. (2017) made impressive claims about being able to value damage from future, high warming by analysing impacts data from about 1950 to 2010. For example, Hsiang et al. (2017, Fig. 5A) estimated 95% confidence intervals for a quadratic US CDF in 2080-99 from warming up to 8°C, with about a 4-9% GDP loss interval from 6°C warming.

As yet, NCEL has had little influence yet on governmental estimates of SCCs – for example, none is cited by IWG (2016) – but the National Academies (2017) review of updating SCC estimation recommended (p.3) "draw[ing] on recent scientific literature relating to...empirical estimation...of damages", as highlighted by Pizer (2017) and Diaz and Moore (2017). Such studies are therefore likely to grow rapidly in number, quality and influence; and they will surely be useful for predicting and minimising damage from *decadal* climate change.

But as shown in [Figure 3](#), the maximum year-to-year variation in global mean surface temperatures during 1950-2010 was only ~0.3°C. So how can NCEL derive confidence intervals for sustained, *centennial* damage from over 3°C warming, and hence improve the SCC that informs emission abatement policies on behalf of distant generations? The answer is: only by analysing the impacts of the much greater



**FIGURE 3.** Global surface temperature anomaly, 1950-2010  
 (<http://www.bom.gov.au/climate/change/>)

variations in temperature, precipitation, etcetera over the much smaller time- and space-scales noted above, and then making assumptions such as:

"... the *marginal treatment comparability assumption*, which requires that the effect of a marginal change in the distribution of weather (relative to expectation) is the same as the effect of an analogous marginal change in the climate" (Hsiang et al. 2017, Supp. Mat. p.9)

Caveats can be found in NCEL papers (e.g. Burke et al. 2015b, p.239; Carleton and Hsiang 2016, p.11) that effectively admit such assumptions are ultimately untestable: we cannot know that the impacts on global human welfare of sustained, massively unprecedented levels and rates of climate change can be reliably predicted by a far-out-of-sample extrapolation from short-run, local analyses. Such assumptions are in effect non-falsifiable beliefs; but rather than dismiss them summarily, as Pindyck (2017, footnote 3) does, let us now consider the CDF knowability problem in detail, and thus show why it is a problem "always".

## WHY CENTENNIAL CLIMATE DAMAGE FUNCTIONS ARE HIGHLY UNKNOWNABLE

Here we illustrate three broad reasons why global, centennial CDFs, as used by IAMs to estimate SCCs, are, and will remain, highly, though not absolutely, unknowable. First, there are no adequate comparators for testing CDFs at the necessary scale; second, there are no

agreed, stable underlying laws that allow SCC modelling with any confidence; and third, slow Earth-system response times greatly limit climate damage learning (how much damage observed decades from now can help predict damage in the century after that). We start by discussing prediction testing in astronomy and selected earth sciences, then in climate science, and lastly in CDFs.

## **Prediction testing in astronomy and selected earth sciences**

A key feature of astronomy, geology, seismology, volcanology and meteorology is that, for the questions they are expected to address, comparisons and hence useful prediction testing are often possible, albeit often by natural, uncontrollable experiments. This in turn depends on scientists in these fields not being expected to make predictions about unprecedented changes in a century's time, and on the systems studied having agreed, stable underlying laws. For example, astronomy is not expected to determine if some intelligent life-form on another planet is threatening its own centennial existence by limitless growth. For the questions it does address, it can potentially compare planets, stars and galaxies with thousands of other planets, stars and galaxies; and the relevant laws of physics are believed, with good evidence, to be stable. Predictions can sometimes be tested by natural experiment, such as the collision of two black holes detected in 2015 that confirmed Einstein's 1915 prediction of gravitational waves (Cho 2016); and no one doubts that any modification by 2115 of the recently laws of general relativity confirmed will still explain all pre-2015 phenomena.

Geology, for those of its chosen questions which cannot be tested experimentally, can compare one part of the Earth with other parts, and mining geologists continually use such comparisons to make testable predictions about mineral locations. Individual earthquakes and eruptions are very hard to predict, but their local, decadal (if not centennial) averages can be predicted, thanks to evidence-justified confidence in the science of plate tectonics. Meteorology generally asks questions over timescales short enough that it can usefully compare events of interest with many similar events, though once timescales stretch to weeks, weather complexity greatly reduces predictability. Meteorology is facing new, difficult questions because of climate change, such as hurricane intensities over unprecedentedly warm seas, but the underlying laws of atmospheric physics are testable and stable.

## **Prediction testing in climate science**

Laboratory testability indeed means "the principles of fluid dynamics, thermodynamics, and radiation that lead to the primary results of global warming under increasing atmospheric carbon dioxide are common to all climate models" (Hargreaves and Annan

2014). For example, the radiative absorption spectrum of CO<sub>2</sub> can be laboratory-tested with great accuracy. But because it entails global fieldwork, the current global atmospheric concentration of CO<sub>2</sub> is less accurately known. And centennial predictions of climate variables cannot be directly tested, because the Earth system is unique, the timescale is centennial, and the system's likely centennial state is dramatically unprecedented, as noted earlier.

The best one can do is build global climate models, and back-test them against instrumental, historical or paleoclimatic records. But because the Earth's biophysical systems are so complex, both the knowability and stability of their "useful laws of motion" – not the basic physics, but higher order measures like climate sensitivity – are much lower than with astronomy or geology. There are also uncertain tipping elements in Earth systems, where small changes in climate forcing may trigger large, irreversible, though in some cases very slow, shifts in climate equilibria (Lenton et al. 2008). Hence climate modellers' confidence decreases as their global, centennial predictions move from mean CO<sub>2</sub> concentration, through mean temperature, to more complex phenomena like precipitation and extremes. Nevertheless, consensus in the underlying methodologies is strong enough that modellers are willing to combine independent predictions into "democratic" model ensembles (Burke et al. 2015a).

Another challenge is from equilibrium response times in centuries or millennia: much longer for melting ice-sheets, hence for major sea-level rise, than for the oceans and the atmosphere (Robel 2015). So whatever may be learnt from testing climate science models in say 2050, humanity then will still have no comparators to test predictions of the unprecedented Earth system changes awaiting their descendants in 2150.

### **Prediction testing in climate social science**

On moving from climate natural science to the climate social science of estimating CDFs, there is another jump in unknowability. A highly globalised population of 10 or more billion people is so unprecedented that evidence of severe climate-change damage on past societies (e.g. McMichael 2012) cannot test any monetary estimate of future damage; and the Earth system including the impact of modern humanity is immensely more complex, thus harder to model, than the system without humanity that climate (natural) science mainly models. Though important progress has been made in analysing complex system dynamics – for example, the effects of network connectivity (Arenas et al. 2008) – such analysis falls far short of any consensus about the nature, or even existence, of stable laws governing how humanity will respond to unprecedented climate change; so disputes will "always" persist.

As evidence, consider some ongoing controversies, all relevant to any centennial CDF: about the effects of geography on centennial development (e.g. Diamond 1997 versus Acemoglu and Robinson 2012); the economic drivers of centennial social inequality (e.g. Piketty 2014 versus Milanovic 2016); and the effects of climate change on conflict (e.g. Buhaug et al. 2014 versus Hsiang et al. 2014). And the slow-response problem again limits what can be learnt from future climate damages, as it does for climate science. Calculations with DICE-2016R project that even once total CO<sub>2</sub> emissions become near-zero, hence CO<sub>2</sub> concentration declines, expected global warming will keep rising for about another century; and sea-level rise will continue for millennia thereafter (Robel 2015 again).

In conclusion, the NCEL claim, that local damage from short-run warming or other geophysical changes can be used to predict global damage from the same changes sustained over many decades in the far future, is untestable. There are no adequate comparators for testing CDFs for unprecedented, likely future warming combined with unprecedented globalisation and population growth. For this reason alone, disputes among climate economists – defined more broadly than contributors to official reviews like IWG (2016) – about centennial CDFs can never be resolved. So we next consider an alternative: carbon prices estimated without using SCCs based on CDFs.

## **CARBON PRICING WITHOUT USING SCC ESTIMATES: THE ROLE OF COST-EFFECTIVENESS ANALYSES (CEAS)**

An SCC's input to policy is just a CBA-base carbon price, or time series thereof. An alternative price is the marginal abatement cost (MAC) from a cost-effectiveness analysis (CEA), used here to mean analyses of low-cost, if not least-cost, policy scenarios that achieve the socially agreed, physical climate targets, usually targets for warming, annual or cumulative emissions, or greenhouse gas concentrations, which are in fact the predominant form of climate policies (e.g. UN 2009, 2015). Since pioneering work like Manne and Richels (1992), scores of CEAs of global and national climate policies have been done, often using IAMs not designed for CBA; see for example Weyant and Kriegler (2014), Kriegler et al. (2015), and studies cited by CPLC (2017, p.6).

Because CEAs do not have to guesstimate a CDF, they can and do analyse more detailed climate policies, not just global carbon pricing. In particular, they can be applied to any jurisdiction where climate policies are chosen, from a nation down to a city, provided the target is either set directly for emissions control, or derived as the jurisdiction's required contribution to a global warming or concentration target. They can also include many details of different economic sectors and emitting technologies.

For example, Luderer et al. (2012) calculated the rise in total mitigation costs caused by delaying until 2020 the implementation of a global climate agreement by all or just some major emitters, and they found that delay until 2030 made stabilising atmospheric CO<sub>2</sub> at 450 ppm impossible. They also showed how restrictions on using some low-carbon energy sources like nuclear or biomass can drive up total costs, and how the transport sector is particularly costly to decarbonise. Bertram et al. (2015)'s CEA focused on the role of "carbon lock-in": how delay in climate action results in building new, long-lived coal-fired electricity generators, hence higher decarbonisation costs after 2030. Also, CEAs seem to result in more model intercomparisons, as for example in Kriegler et al. (2015) and Bertram et al. (2015), in contrast to well-known, single-author meta-analyses of SCCs, as critiqued by van den Bergh and Botzen (2015).

CEAs are no panacea, though. CEA-based IAMs may maintain the "veneer of scientific legitimacy" that Pindyck (2017) criticises in CBA-based IAMs. Important, deep uncertainties still face any IAM, including how fast economies might grow (e.g. Gillingham et al. 2015) and how fast carbon abatement costs might fall (e.g. Kriegler et al. 2014), over a century or more. (However, price changes in current carbon markets can give some guidance on abatement costs (Dietz and Fankhauser 2010), which market prices cannot do for CDFs.) Key ethical debates remain in CEA as in CBA: about the difference of a US dollar cost imposed on rich versus poor countries; or on current versus far-future generations, as calculated by the (social) consumption discount rate chosen (e.g. van den Bergh and Botzen 2015).

Also, as the unavoidable counterpart to the high unknowability of climate damage functions in CBAs, physical climate targets, whether for emissions, concentrations or temperature, are hard to agree on (e.g. Hallegatte et al. 2016). A CEA-based MAC cannot be proved to be economically optimal, precisely because of damage unknowability, though neither can a CBA-based SCC, as argued above. Aiming for a lower warming limit must take into account its extra abatement costs, while also recognising that abatement costs being more reversible than damage costs supports a precautionary approach (Hallegatte et al. 2016, p.667; see also IPCC 2014, SPM 3.2).

My recommendation of much more use of MACs and less of SCCs as bases for carbon pricing is thus mainly because MACs are available for a much wider range of regional and sectoral abatement policies, and because the supposed optimality of SCCs is illusory. But in closing, we must consider why this recommendation may well be problematic for economists and hence strongly resisted.

## **WHY THIS CHALLENGE TO THE SOCIAL COST OF CARBON IS PROBLEMATIC TO MANY ECONOMISTS**

One obvious reason why so many economists calculate SCCs and want to improve them is because some governments require them, notably the US government in its Executive Order 12866 (Clinton 1993). EO12866 mandates that "...in choosing among alternative regulatory approaches, agencies should select those approaches that maximize net benefits"; it is in the title of the US inter-agency determination of the SCC (IWG 2010, IWG 2016); and it is cited often (e.g. Pizer 2017). Yet it also states that "costs and benefits shall be understood to include...qualitative measures of costs and benefits that are difficult to quantify, but nevertheless essential to consider." So the US government could conceivably, though improbably, give a "reasoned determination that the benefits...justify [the] costs" of minimising the risk of dangerous climate change by setting a precautionary, physical climate target.

Another reason why climate economists calculate SCCs is that they are trained to do so. Switching to CEA-based MACs may be seen as abandoning the economist's professional mission to maximise welfare by equating marginal costs with marginal benefits. Some policymakers and campaigners may also fear that emission control will be harder to argue for in public debate if its benefits are not valued monetarily, however contentiously. More speculatively, many economists and some policymakers they advise may be psychologically attached to believing that SCC estimation can be significantly improved. At a deep level, humans' understanding of their very sense of existence is perhaps shaken by centennial climate change (Boulton 2016), and it is probably less scary to believe that cost-benefit estimates can usefully advise us, than to accept that we can never be sure how dangerous is the one-off, uncontrolled experiment that humanity is conducting on Earth.

## **CONCLUSIONS**

I have argued above that a centennial climate damage function, which any integrated assessment (global climate-economy) model needs in order to derive a cost-benefit-based social cost of carbon (SCC), is so deeply uncertain or "highly unknowable" that there will always be disputes about the SCC. One cause of high damage unknowability is incomparability, because of the uniqueness of the Earth system (including humanity) combined with the dramatically unprecedented level and speed of likely centennial climate change. By contrast, examples from non-experimental sciences like astronomy and geology showed how these sciences can find comparators for the questions they tackle. Another key cause is the huge complexity of possible human behaviour in the future Earth system. This means there are no agreed, stable laws to use in modelling centennial climate damage,



in contrast to centennial climate science, even though the complexity of the climate system without humanity still poses daunting challenges to modellers. Advanced statistical analyses of past "weather" effects on national or regional economies are rapidly improving, but claims that they can significantly improve climate damage functions rest on untestable beliefs that such analyses can be extrapolated far out of sample to the global, centennial scale needed for climate policy.

So instead of basing the carbon prices used in various climate policies and other regulations on SCC estimates, there is a strong case for basing more carbon prices on the marginal abatement costs derived from cost-effective paths, calculated with other integrated assessment models, that achieve socially agreed, physical climate targets. Such derivations are still highly uncertain, and downplaying the cost-benefit approach to carbon pricing will pose political, professional and psychological challenges to many economists, in addition to the obvious difficulty of agreeing physical targets. Nevertheless, a cost-effectiveness approach avoids the illusion of centennial optimality, and is more consistent with the target-based nature of many climate policies.

### **Acknowledgments**

I thank Nerilie Abram, Paul Burke, Simon Dietz, Paul Francis, Chris Hope, Mark Howden, Paul Kokic, Sophie Lewis, Penny Sackett and Gernot Wagner, and particularly Quentin Grafton, Michael Grubb, Will Steffen, Mike Toman and Jeroen van den Bergh for helpful comments; and I thank Clive Hilliker for technical assistance with the Figures. The usual disclaimer applies.

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