4

How Some Economic Analyses Have Distorted the Issues

We have already come a long way in this book in setting out the scientific and economic analyses of the magnitude of the risks from climate change, and in showing how responsible climate policy can combine with economic growth and the battle against poverty. This combination can generate a new and sustainable pattern of economic development and prosperity. We have described the policies that can foster this change. Much of the economic analysis of climate change, however, has gone in other directions. Thus it is important to examine that analysis. I shall argue that much of it has been misleading or misguided. The main purpose of this chapter is to examine the models (the integrated assessment models or IAMs) that have been prominent in the literature and which try to combine climate science with modeling of economic impacts of climate change. Such a combination is a worthy endeavor and the IAMs have played a useful role, inasmuch as they provide an explicit approach to this combination.

However, in my view they have played a confusing role in discussions of policy, because the picture most of them have painted is an outlier in the range of possibilities and very far from being a central case. Unfortunately, because the IAMs have been prominent, they have been taken by many, erroneously, as depicting a central case or overall consensus. The basic problem is that they have assumed strong underlying growth, *plus* only modest damages from big increases in temperature, *plus* very limited risk. All these are really direct assertions rather than based on serious and relevant evidence.[1] Thus the models have basic assumptions which imply that unmanaged climate change will cause relatively small losses to incomes that will be much higher in the future. That essentially assumes away the need for strong and urgent action.

Some of these problems are inherent in the type of modeling. Others derive from the particularities of the assumptions made within the model. Given the dominance of such models in the discussions of the economics of climate change, it is important to look a little more closely at some of their details to see how the problems arise. In so doing we can shed light on how to handle theory and modeling in this area of economics. We start in section 4.1 with the underlying science of the risks. This takes forward the discussion of chapter 1 but emphasizes in particular the inherent conservatism of the models in the sense of their omitting some very important risks. The main focus of this chapter, however (in section 4.2), is the way in which much economic modeling has grossly underestimated the potential damages and risks from climate change.

At some points in this chapter, in discussing the models, a little mathematics and formalization is unavoidable. I hope the less mathematical reader will not be deterred. The arguments concerning the bias in the economic modeling are important, and the gist should be accessible without poring over the mathematics.

4.1 Science and science modeling: inherent conservatism

There is a very important disconnection between the scale of the risks arising from anthropogenic climate change, the potential consequences of human action, as described by scientists, and what many of the formal scientific models are telling us about the likelihoods and impacts. At various places I focus on temperature increases of 4°C or more because such temperatures have substantial probabilities, more than 50% in some emissions scenarios, have not been seen for tens of millions of years, have potentially devastating impacts, and yet, at least in some IAM modeling, are presented as involving only modest losses. Where 4°C is used, it should not be taken to imply that temperatures below that involve only weak damages. On the contrary, we have not seen 3°C for around 3 million years, and its consequences could also be extremely damaging. Indeed climate scientists have understandably used 2°C as the threshold for dangerous climate change.

4.1.1 Climate models: "The climate we get if we are lucky"[2]

Climate models usually attempt to make general statements about processes such as temperature increases and sea level rises. They generally leave out many effects, recognized as potentially very large, that are not easy to make precise or formal enough for integration into the mathematical modeling.

Climate scientists have, of course, long been keenly aware that their models leave out much that may be of profound significance, and many have discussed these omissions and their possible consequences. Sometimes such discussions are linked to or expressed in terms of "tipping points."[3] Over the past three decades many more of these processes, or better representations of them, have been included as climate models have developed. But many are still omitted.

Leaving something out of a model for reasons of our inability to model it satisfactorily is understandable, indeed reasonable. In fact the essential point of using models in the first place is that they leave out many things in order to focus on others. But we then have to ask whether their focus is on what matters most for the problem at hand. Drawing attention to the omissions is not to criticize the builders of the models; but omissions from a model should not imply omissions from the argument.

Potentially key factors or effects still generally omitted from climate models include:

- thawing of the permafrost with consequent release of methane,
- collapse of land-based polar ice sheets,
- release of seabed methane,
- complex interaction with ecosystems and biodiversity more generally.

Other key factors that are represented in some of the climate models, but where the range of risks might be understated, include:

- ocean acidification and associated feedbacks,
- collapse of the oceanic thermohaline circulation,
- collapse of the Amazon and other tropical forests,
- potential for chaotic and unstable behavior of complex dynamical systems.

We cannot say precisely what risks are associated with the omitted factors when they are taken together and combined with those features that are represented, or underrepresented, in the climate models; but it seems reasonable to suggest that they could add greatly to the risks indicated by the existing climate models. And it would seem extraordinary to say that we can be confident that the risks associated with the omitted factors are negligibly small.

It is also of concern that key examples from past climate history generally fail to emerge in current models. Examples are the rapid transformation of the "green" Sahara around 9,000 to 5,000 years ago and the collapse of the Atlantic meridional overturning circulation during the glacial period 120,000 to 12,000 years ago.[4]

There are various research programs that aim to push the models forward—for example, the EU-funded EMBRACE project, planned modeling work at the UK Met Office Hadley Centre on methane emissions and ice sheets on land, and a range of research on extreme events. See box 4.1 for examples of research to improve the models.

4.1.2 Impact models: more omissions, overfocus on the tractable, inadequate focus on impacts on lives and livelihoods

Impact models, and the way they tutor policy, offer a somewhat different set of worries. Impact models are based on the climate models but attempt to quantify impacts on lives and livelihoods by extending broad statements concerning, e.g., temperatures and sea levels to more regional or local effects such as desertification, rainfall patterns, potential agricultural outputs, etc. The problem with many important models has been that the focus has been on the tractable, rather than on the effects of climate change that are likely to be of most importance for people's lives and livelihoods. Factors affecting lives and livelihoods, mostly involving water (or the lack of it) in some shape or form, include the following. We concentrate on examples for 4°C and above, but strong and catastrophic events are likely to come through at lower temperatures too.[5] See box 4.2 for more detailed descriptions and references.

- *Desertification, droughts, and water stress*. Much of southern Europe may come to look like the Sahara Desert, much of the snow and ice on the Himalayas, the Andes, and the Rockies may be gone, and there may be profound effects on water availability for billions of people.
- *Changing patterns of precipitation and temperature*. The North India monsoon, which shapes the agricultural lives of hundreds of millions, may be radically altered. There may be severe flooding from intense

Box 4.1

Examples of research programs that aim to push the models forward[6]

The EU-funded EMBRACE project (work package 5) aims to "identify and assess processes that may result in abrupt or irreversible climatic changes." This work package uses Coupled Model Intercomparison Project Phase 5 (CMIP5) Earth system models, including the UK Met Office HadGEM2-ES model, to simulate better some potentially abrupt/irreversible systems. They do not simulate all potential thresholds/tipping points, but sea ice, Atlantic meridional overturning circulation, and tropical forest systems are being included, and a series of experiments are being run. This work includes development of an early warning toolkit to predict abrupt change by analyzing change in variability that precedes the abrupt change.

Work at the UK Met Office Hadley Centre aims to estimate permafrost emissions offline and add them back into the HadGEM2-ES model to explore the feedbacks (on permafrost emissions see, e.g., Burke, Hartley, and Jones 2012; Schneider von Deimling et al. 2012). This work is in conjunction with the COMBINE project that will explore other missing feedbacks. There has also been initial work using HadGEM2-ES to investigate potential consequences of an abrupt methane release from ocean hydrates; and wetland methane emissions are now included in HadGEM2-ES.

Thresholds for ice sheets on land, currently not included in HadGEM2-ES as it does not include a dynamic ice sheet model, will be included in the new Earth system model UKESM1 currently under development. Ocean circulation (see, e.g., Hawkins et al. 2011; Weaver et al. 2012), tropical forests (see, e.g., Good et al. 2013; Murphy and Bowman 2012), and changes to the hydrological cycle (see, e.g., Good et al. 2012; Levine et al. 2013) are also being investigated with HadGEM2-ES.

Research on extreme events is progressing and includes tropical cyclone tracking, forest fire danger indices, new models of drought in Africa, the ISI-MIP model intercomparison project for impact models, regional modeling (downscaling), and anthropogenic aerosol effects on Atlantic hurricane frequency (on extreme events see, e.g., Hansen, Sato, and Ruedy 2012b; Rahmstorf and Coumou 2011; Dole et al. 2011).

Box 4.2
Factors affecting lives and livelihoods

We look to scientists to provide some clues on the nature of climate risk. Based on the mainstream scientific literature, at a global average temperature increase of 4°C or more we might have to consider the following:

- Much of southern Europe may experience drying and desertification (Solomon et al. 2009); the Sahara might advance southward with possibly profound effects on the populations of northern Nigeria, with pressure on people to move south. Increased desertification in Mexico could put pressure on populations to move north (IPCC 2012).
- Much of the snow and ice on the Himalayas would have gone, with possibly radical effects on pattern and timing of flows in the rivers that serve one or two billion people, and with rapid runoffs, major flooding, and soil erosion on a massive scale (Kaltenborn, Nellemann, and Vistnes 2010; World Bank 2013a).[7]
- Similarly, the melting of snow and ice on the mountain chains of the Andes and Rockies could dramatically alter water supplies to the western regions of South and North America (Kaser, Großhauser, and Marzeion 2010; Kaltenborn, Nellemann, and Vistnes 2010) as well as to the Amazon River. More precipitation would fall as rain rather than snow, reducing water storage and increasing flooding. Many models suggest profound effects on global water availability for billions of people, with likely significant impacts on agriculture and ecosystems (e.g., Solomon et al. 2009).
- The North Indian monsoon which shapes the agricultural lives of hundreds of millions may be radically altered. Although there are a number of models that can simulate the current Indian summer monsoon (see e.g., Annamalai, Hamilton, and Sperber 2007), such models may underrepresent potential future changes (see Valdes 2011), which could be sudden and dramatic.
- The Amazon forest might die back at radically altered climates, with the release of huge amounts of CO_2, and, e.g., possible desertification of much of the heavily populated state of São Paulo (Kriegler et al. 2009; Cook and Vizy 2008; Jones et al. 2009; Malhi et al. 2009; Huntingford et al. 2013; World Bank 2012b).
- Extreme weather events (e.g., storms, cyclones) are likely to be more intense. Tropical cyclones take their energy from the seas, and higher temperatures make the winds stronger: damages go up by approximately the third power of wind speed (Emanuel 1987; Knutson and Tuleya 2004; IPCC 2012; World Bank 2012b and 2013a).
- Storm surges could result in salination of large areas and their effective loss to agriculture (Agrawala et al. 2003) and in grave damage to low-lying regions.

Box 4.2 (continued)

- Global sea levels rise slowly with thermal expansion, but the effects could be massive. In the Pliocene epoch around 3 million years ago, when temperatures may have been 3°C or so warmer than in preindustrial times, sea level was around 20 meters higher than now (Miller et al. 2012). It has been estimated that up to 200 million people might be displaced by a 2-meter rise (Nicholls et al. 2010): current projections suggest a 2-meter sea level rise might occur sometime by the end of this century. Many low-lying countries and coastal cities across the world would be profoundly affected. Effects could come through much more quickly than the slower timescales indicated by thermal expansion if land-based ice slides into the oceans—an effect looking increasingly possible but not yet included in the formal science models (van der Veen 2010).
- Heat stress could sharply increase. Wet bulb temperatures[8] above 35°C induce hyperthermia and death in humans as the dissipation of metabolic heat becomes impossible. Wet bulb temperature is the temperature measured by a thermometer with the bulb wrapped in wet muslin (formally it is the temperature of "adiabatic saturation," or the temperature a parcel of air would have if it were cooled to 100% of humidity using latent heat from within the parcel). It is always above dry bulb temperature (except at 100% humidity), which is normal air temperature (often above 35°C in certain regions). The difference between these two types of temperature is a measure of relative humidity. Wet bulb temperatures above 35°C are likely to start to occur in small zones at global temperature increases of around 7°C. At 11–12°C increases, these zones would expand to encompass the majority of today's human population (Sherwood and Huber 2010). At those temperatures, most of the planet may become almost uninhabitable, with large areas becoming uninhabitable as we move in this direction.

precipitation and changing river flows, along with erosion and loss of tree cover. Local heat stress may become more common as temperatures rise.

- *Collapse of forests and biodiversity*. Rainforests such as the Amazon might die back in dramatically altered climates, releasing huge amounts of CO_2, with potentially runaway feedbacks, and risking desertification in key regions.
- *Extreme weather events*. These are likely to be more intense, e.g., storms, cyclones, etc., with much higher wind speeds; damage increases very rapidly with wind speed.
- *Storm surges from seas and oceans*. This could result in large-scale destruction of buildings and infrastructure, and salination of large areas and their effective loss to agriculture.
- *Global sea level rise*. Sea level may rise slowly with thermal expansion, but the effects, such as permanent submergence of land, could be massive. Effects could come much more quickly if land-based ice slides into the oceans.

Impact models incorporate some of these factors with different degrees of credibility, but other factors are usually missing from models altogether.[9] On the whole, I would suggest that the models fail to come to grips with the overall scale of the risks associated with the possible phenomena described at temperature changes of 4°C or more (or indeed at some lower temperatures). The scale of impacts in this scenario could mean that hardship is intense and widespread and, in many cases, could imply movement of people in very large numbers. Key to a lot of these modeling problems is that the impact is local, yet many climate factors operate at a global level where the links to the local are not easily captured. The resolution necessary for much of the relevant local modeling (bearing in mind the strong links to the global structures) strains information, modeling capacity, and computation beyond their limits. Climate models are better at simulating large spatial scales and longer-term averages than local or short-term extremes.

The underassessment of risk in the science models implies that we need not only a new generation of models, but also a broader and wiser set of perspectives on how to use the models that we have.

4.2 Integrated assessment models (IAMs)—further underassessment of risk

Starting in 1991 with pioneering articles by Bill Nordhaus on the economics of the greenhouse effect,[10] and with Bill Cline's 1992 book *The Economics of Global Warming*, economists have tried to build models that can inform policy on climate change. Integrated assessment models, as they have become known, attempt to integrate the science of climate change with economic modeling and go beyond the narrow cost-benefit analysis project or program approach. They have produced valuable insights.[11]

There has been growing concern, however, and I think justifiably so, that these models have major disconnections from the science in the way they have been constructed and the assumptions they embody.[12] Indeed, economist Robert Pindyck argues that the models tell us very little and "create a perception of knowledge and precision, but that perception is illusory and misleading."[13] Tim Lenton and Juan-Carlos Ciscar review the limitations of the models and state that there is a "huge gulf between natural scientists' understanding of climate thresholds or tipping points and economists' representations of climate catastrophes in integrated assessment models."[14] Frank Ackerman and Elisabeth Stanton also review the limitations of the major models and state: "an examination of … three models [PAGE, DICE, and FUND] shows that current economic modelling of climate damages is not remotely consistent with the recent research on impacts."[15] They point out that these models were used by the US Interagency Working Group in 2010 to estimate the social cost of carbon (SCC), for use in cost-benefit analysis of US regulations, at \$21/tCO_2.[16] This was recently revised upward to around \$35/tCO_2.[17] That number is far better than zero, but the point is that estimates based on these models are very sensitive to assumptions and are likely to lead to gross underestimation.

There are very strong grounds for arguing that they grossly underestimate the risks of climate change, not simply because of the limitations of climate and impact models already described, but because of the further assumptions built into the economic modeling on growth, damages, and risks, which come close to assuming directly that the impacts and costs will be modest and to excluding the possibility of catastrophic outcomes altogether.

4.2.1 Assumptions that drive the underestimation

Even though there have been advances in economic modeling and models differ in their assumptions, four basic features of the economic models have remained largely unchanged since the early stages of their development: (1) the presence of underlying exogenous drivers of growth (in aggregated one-good models); (2) damage functions (usually but not always multiplicative) that relate damage to output in a period to temperature in that period only; (3) quantitatively weak damage functions; (4) very limited distribution of risks.

I have argued above and in the literature that in-built assumptions based on growth, damages, and risk result in gross underestimation of the costs, impacts, and the overall scale of the risks from unmanaged climate change.[18] The problems in economic modeling arise directly from these basic assumptions on the modeling of growth and climate impacts. To demonstrate, I need to go into some of the formal expression of the models. The less mathematical reader should not worry about the detail.

A general functional form in such models presents output, H, at time t as a function F of production inputs as follows:

$$\text{Output} = H = F(K, N, L, t, T), \tag{4.1}$$

where K is capital, N is labor, L is land, and T is temperature, all at time t (each of K, N, L could be vectors). This formulation involves a crucial separability across periods—i.e., output depends only on variables at time t, including temperature. Damages from earlier climate change resulting in reduced K in this period could be indirectly included in these models if they occur through an influence on previous savings via damages to previous output. However, in these models such savings effects are generally small;[19] and savings could be increased by anticipated future output damage. In reality capital, labor, and land in this period could be influenced by earlier direct damage, for example by the effects of a hurricane or flood in a previous period, and such direct effects are rarely incorporated in the models, or if they are, they are assumed to be small. Damages are usually modeled as loss of output flow rather than damages to stocks.

A further separability arises if output is written as a product of a multiplicative factor b, depending on time t and temperature T, and a "production function" depicting the direct effect on output of capital, labor, and land:

$$H = b(t, T) \cdot F(K, N, L). \tag{4.2}$$

Still further separabilty is often imposed on the function when growth from technical progress is specified as an element that is exogenous[20] and multiplicative, as represented by $f(t)$. This can be multiplicatively combined with a damage function, $D(T)$ representing proportional output losses of temperature T, which has an effect on output, via $(1 - D)$.[21] These are included as follows:

$$H = f(t) \cdot (1 - D(T)) \cdot F(K, N, L). \tag{4.3}$$

From there, $f(t)$ is often specified as embodying exponential growth at rate g and takes the form Ae^{gt}, where g is often, but not necessarily, seen as constant over time.[22] The damage function $D(T)$ is often a simple power function, or a quadratic.[23] Damage functions are often calibrated by forcing them to fit current temperature and one other temperature point (delivering the estimate of at most two parameters).

4.2.2 Damages and growth

For much of Nordhaus's work using the DICE model,[24] the loss via $D(T)$ at 5°C is in the region of 5–10% of GDP (figure 4.1).[25]

Most reasonable modelers will accept that at higher temperatures the models go beyond their useful limits; Nordhaus suggests that we have insufficient evidence to extrapolate reliably beyond 3°C.[26] These models are not equipped to deal with the kinds of temperature changes and the possible impacts that scientists are worried about. Yet if the science tells us that, for a number of possible emissions paths, there are major risks of temperatures well above 3°C, we have to try to think about such consequences in assessing policy. And given that the world may not have seen 3°C for the past 3 million years, we have to wonder whether these IAM models give an adequate account even of the risks associated with 3°C. To illustrate the difficulties encountered, while recognizing the wise cautionary advice of Nordhaus on making such extrapolations, it can be shown[27] that in a standard model,[28] temperature increases of as much as 19°C might involve a loss in output of only 50%, against a baseline where the world is assumed to be many times richer by 2100 (table 4.1).

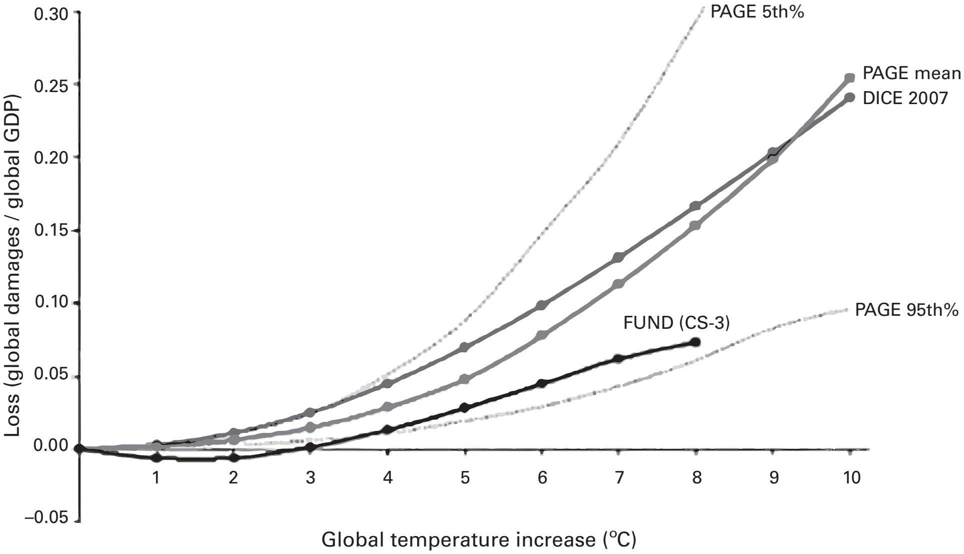

Figure 4.1
Annual consumption loss as a fraction of global GDP in 2100 due to an increase in annual global temperature in the DICE, FUND, and PAGE models. The horizontal axis represents increase in average global surface temperature (relative to the second half of the nineteenth century), and the vertical axis the fractional damages from climate change as a proportion of output. Source: Interagency Working Group on Social Cost of Carbon (2010).

This illustrates both the extremely modest nature of damages assumed in such models and the perils of such extrapolation—in fact, such temperatures could involve complete human extinction, as indeed could much smaller temperature increases (see box 4.2 on wet bulb temperatures). In this context the damage functions in the literature, portrayed in figure 4.1, are simply absurdly low.

Some have responded to the apparent absurdities of such weak damage functions by invoking higher-order terms in the expression relating damages to temperature.[29] These are steps in a sensible direction,[30] but the models still appear to suffer from the omission of the scale of damage that could arise from catastrophes, mass migration, and serious conflict; most retain exogenous drivers of growth, and most have inherently narrow risk descriptions (although see below on Weitzman's work).[31] Most of them have population determined exogenously to the model (i.e., whatever the nature and magnitude of the impacts of climate change,

Table 4.1
Output levels in year 100 relative to now, given specified growth rates and rates of output loss (base value = 100; output loss in parentheses)

Growth rate	With output loss of:				
	0%	5%	10%	20%	50%
1%	270	256 (14)	243 (27)	216 (54)	135 (135)
2%	724	688 (36)	652 (72)	579 (145)	362 (362)
3%	1,922	1,826 (96)	1,730 (192)	1,538 (384)	961 (961)

Note: an entry in the table depicts what output would be after a century of growth at the rate indicated by the row, adjusting for a percentage loss indicated by the column. Thus for a 0% loss and 1% growth rate, output would be 270, compared with a base value output of 100; for a 10% loss at the same growth rate, output would be 243, with a loss of 27.

the model does not allow for any impact on the size of population), which makes these models unable to examine what may well be the most important consequence of high temperatures, namely migration, conflict, and large-scale loss of life. Thus in this crucial aspect too they miss the key points raised by the problem we are trying to understand. Essentially worries about climate change are, in large measure, associated with considering the catastrophic damages that could result from temperatures near or above 4°C or 5°C, yet these models directly assume away such catastrophic outcomes. They simply miss the crucial point; they do not really examine the problem at hand. Yet they are often portrayed as providing appropriate or central estimates of costs of climate change.

We should note that not all the models are the same, and we use the separability assumption in the form of growth effect times damage effect times output for expository purposes only.

The key point is not so much constancy or separability but the exogeneity of a key driver of growth combined with weak damages. With exogenous growth that is fairly high (say at 1% or more over a century or more) and modest damages, future generations are more or less assumed to be much better off (table 4.1).[32] With a 2% growth rate and damages at 20%, far higher than the "standard" model of DICE (Nordhaus) even at 8°C, the output 100 years on would be 579, or nearly six times that of now. Thus we would be assuming those alive in 100 years would be much richer than we are, and it is natural to regard even a

20% loss for them (reducing output from 724 to 579) as minor relative to costs occurring now. But at a global increase of 8°C, it is likely that much of the world now inhabited could not be inhabited and much of the human race would have been wiped out.

Exogenous growth of any long-term strength is simply not credible in the face of the scale of the disruption that could arise at these higher temperatures. Potential large-scale destruction of capital and infrastructure, mass migration, conflict, and so on can hardly be seen as a context for stable and exogenously growing production conditions; see below for further discussion of risk, or its relative absence, in these models.

4.2.3 Ways forward in modeling aggregate damages[33]

While I shall argue that we need a broader range of models and perspectives, we should also ask how we can do better within the context of models based on aggregate output. There has been some recent progress which focuses on effects of climate change on the growth rate itself or on factor productivity (i.e., damages which deliver a permanent "kick downward" in the production function).[34]

Here are four ways in which the scale and long-lasting effects of damage might be incorporated in formal modeling based on the insights of standard production and growth theory.

1. *Damage to social, organizational, or environmental capital.* We can think of social, organizational, or environmental capital as further arguments in the production function $H(\ )$. These forms of capital—and the knowledge, structures, networks, and relationships that they represent—could suffer permanent or long-term damage from hostile climate and extreme events and by migration, disruption, and conflict.

2. *Damage to stocks of capital or land.* Climate events such as storms or inundations can do permanent or long-term damage to capital and land. If it is necessary to abandon certain areas, those areas' capital, infrastructure, and land have zero use value and are essentially lost. This could be incorporated in the model via permanent damage or a reduction in capital occurring in period t as a result of temperature and events in that period. An equation relating the stock of the relevant capital $K(t + 1)$ in period $t + 1$ to the stock in period t could have a term

$(1 - \delta(T))K(t)$ where the function $\delta(T)$ denotes the loss of this type of capital in period t. An analogous modeling could apply to social, organizational, and environmental capital.

3. *Damage to overall factor productivity.* While relevant capital stocks might survive, the ability to use them effectively might be damaged by a hostile environment. For example, water infrastructure, even if it survived unscathed from climate events, might be much less productive if the water flows for which it was designed have changed radically. With constant returns to scale, damages which occurred to all capital stocks and factors in equal proportion would have the effect of a permanent reduction in an overall multiplicative factor on total output. In terms of equation (4.2), we might imagine that in $b(t, T)$ the T argument is a vector containing past as well as current temperature.

4. *Damage to learning and endogenous growth*. Theories of endogenous growth usually relate productivity to experience. This could be, for example, experience of investment or of production. Essentially we try to model learning processes. If our experience is related to previously fairly stable circumstances, then the learning it embodies might become much less relevant if those conditions changed radically (agriculture or fisheries could be examples). If investment is mostly repair and replacement, it may carry much less learning than investment that involves innovation and new ideas. Thus climate change could undermine the key drivers of endogenous growth and thus the growth rate.

All four of these ways could lead directly to different production and damage specifications for economic modeling. The basic point that should be incorporated is that the impacts of climate change can cause lasting damage to capital stocks, to productivity, and to growth rates; current models where this lasting damage is omitted are likely to be deeply misleading. However the damage is incorporated, for high temperatures we must consider damages of far greater quantitative substance than those of most of the current literature as represented in figure 4.1.

The extension of modeling work suggested is indeed worth pursuing. However, I should emphasize that the narrow dimensionality of models whose focus is on one form of output will inevitably narrow the models' perspective and leave out many important risks.

4.2.4 Risk

For most of the IAMs, risk plays a very limited role. The PAGE model has more focus on probability distributions than most others, but its probability distributions have been largely shaped by trying to straddle existing models, with a tightly bounded range. The models themselves pay little attention to the potential scale of the risks likely to be embodied in the phenomena being analyzed. Only if these models were run probabilistically, with wide probability distributions over important parameters including those influencing growth, temperature, and damages, could these models be capable of producing futures that are as dismal and destructive as climate science suggests may be possible.[35]

This is a point rightly emphasized by some through the focus on "fat-tailed uncertainty," in this case in the sense of substantial probabilities of high temperatures with very damaging consequences.[36] To focus on tails, however, suggests a remoteness of the potentially huge risks that may be misleading. I would suggest that there are immense problems arising from the middle of distributions (say 4°C or so on some extrapolations of emissions):[37] such problems are not tail effects. The tail is even worse: at 8–10°C, possible a couple of hundred years from now under high emissions scenarios, we might have to recognize possibilities of extinction of much of the human race. It is simply daft or worse to present that as a 15–20% loss to GDP as portrayed in figure 4.1.

Taken together, the assumptions in most IAMs that we have highlighted lead not just to low estimates of the social cost of carbon but to recommendations that we should head for concentrations of, say, 650 ppm CO_2e.[38] The science tells us that there are immense risks at these concentrations; but some economic models apparently tell us that heading for these concentrations is optimal. It is not "economics" that is saying this but the peculiar assumptions generally used in a very narrow class of models.

4.3 Dimensionality

Given the scale and nature of the phenomena at issue, a focus on GDP or aggregate consumption is surely far too narrow to capture our concerns about consequences. The history of the collapse of the Mayan civilization is written as one of failing to understand and act on the risks; such history understandably focuses first on mass population decline, not only or primarily on a fall in output. The GDP of Europe during the Second World War does not by itself illuminate the real tragedy of that war, with over 50 million dead (military and civilian). China's recorded GDP during the Great Leap Forward and Great Famine (1958–1962) fell by 4–5% per annum, but this does not convey the social trauma and extreme loss of life; around 20–30 million or more people died.[39]

Aggregating lives into aggregate income or consumption via a price of a life, as some of the economic models do, gets us into great philosophical difficulties.[40] It is surely more transparent and arguably more, not less, rigorous to analyze possible consequences on a number of dimensions, rather than force an aggregation into a measure like GDP or aggregate consumption that would bury or conceal some very problematic issues. The environmental ecosystem would surely be another highly relevant, indeed central, such dimension. This broader approach may make simpleminded optimization more difficult, but that follows from the nature of the issues at hand.

4.4 Conclusions

"To slow or not to slow,"[41] the title of a pioneering 1991 article by Nordhaus, and its subsequent development into the dynamic DICE model have given us what seems to be a coherent and powerful framework for assessing the costs and benefits of climate change mitigation.[42] But one cannot and should not expect a single model to capture all relevant issues, particularly when they are potentially as extreme and multidimensional as those involved here, and neither should we expect to be able to resolve all difficulties within a single framework.

An examination of the core detail of the economic models highlights a number of key lessons that can help us understand the relevance and usefulness of the models and whether the conclusions they imply are helpful or misleading. In particular we should ask, given the analyses from the science and economics of chapters 1, 2, and 3, whether these models capture or are capable of capturing the key policy issues which arise from the immense potential risks of climate change.

In summary, the lessons we have learned from this chapter are:

- Combining climate science and modeling of economic impacts from climate change is a useful endeavor, but most integrated assessment models (IAMs) mislead and misguide policy discussions because they assume damages from given temperature increases which appear to be implausibly small. For example, a number of models assume damages from a temperature increase of 5°C as 5–10% of GDP or lower (see figure 4.1) when such temperatures have not been seen for tens of millions of years and could be devastating for much of the planet, with consequences potentially including vast movements of populations and severe conflict. And in these models damage from climate change in a given year is for output in that single year only—it does not destroy capital. The results from most of them represent only an outlier position relative to possible outcomes and should be seen as very far from a central case or a reasonable consensus.

- The models further understate total damage from inaction on climate change because they fail to capture the overall scale of risks; in other words, they assume rather narrow distributions. As we saw in chapter 1, the distribution of risk should include the possibility of some very high temperatures with potentially catastrophic effects on a global scale.
- The models are one-dimensional in the sense that they focus on aggregate consumption or output with exogenous population. Yet potential extreme damage to the environment and potential large-scale loss of life are at the core of the questions. Thus, fundamental issues are excluded by assumption.
- The models generally assume exogenous underlying drivers of growth. Given the scale of the potential disruption from climate change, exogenous positive underlying growth is peculiar and unjustified.
- Many of the models assume high pure-time discount rates, thus embodying strong discrimination by date of birth. Discounting issues are discussed in the next chapter but they add another, merely asserted, bias against strong action.
- On the basis of these criticisms and examining model structures, we can see some ways to make the models more plausible and less biased, and some recent papers explore these. However, some aspects of the basic structures militate against their ability to incorporate the great risks and loss of life that could be involved.
- In thinking about how to tackle climate change, we will need a much broader and deeper understanding than embodied in IAMs and in much

of public discussion heretofore. And we will need to probe more deeply into strategies for reducing the risks while fostering a new form of growth. That is not only deeper but also more realistic. It can get much closer to the heart of the issues. The great issues and questions around climate change cannot be shoehorned into a narrow class of IAMs.

Where do we go from here? Essentially, we need a new generation of climate, impact, and economic models. We have to embrace many models, each with its own insights. They should be capable of speaking about the scale of risks we face. Specifically, economic modelers should abandon the assumption of damages being focused on current output and should incorporate lasting damage in the models. They should embrace a real possibility of creating an environment so hostile that physical, social, and organizational capital are destroyed, production processes are radically disrupted, future generations will be much poorer, and hundreds of millions will have to move and many may perish.

But we also have to make policy in real time while we are trying to build better models and learn about the many underlying uncertainties. That is part of the art of policy advice, policy modeling, and policy decision-making. The stakes are so high and the modeling difficulties so intense, when dealing with climate change, that we face the difficulties and tensions of real-time policy making and model improvement in extreme form.

In this light, it is encouraging to see that a number of economists—notably including Bill Nordhaus and Marty Weitzman—are updating their approaches with a greater focus on just how big the effects of climate change could be.[43] In his 2011 book *Climate Casino,* for example, Nordhaus has revised his DICE model, producing higher estimates of the social cost of carbon and the “optimal” pace of mitigation he calculates. Moreover, he dwells at length on the important areas of climate risk that the model cannot capture, because they cannot be monetized. Weitzman makes the risks of immense catastrophes in some possible outcomes central to much of his modeling.

Crucially, also, we need greater judgment in using the economic models. As the late Frank Hahn used to say, “a model is just a sentence in an argument.” We need more and better sentences which embody more of the risks at the heart of the problem, including other dimensions that better capture our concerns about consequences, such as loss of lives. In exercising the judgment necessary in putting the sentences together, one should remember the remark attributed to John Maynard Keynes: “It is better to be roughly right than precisely wrong.” In particular, it is time for the economics profession to think much more carefully about processes of damage and destruction. We have considered theories of growth and have produced valuable insights. We should combine these insights with an examination and modeling of ways in which disruption and decline can occur.

In these circumstances, it is vital that we treat policy analysis as that of a risk management problem of immense proportions and discuss risks in a far more realistic way. We know that models leave out much that is important—that is what makes them models. To draw attention to omissions from models is not necessarily to criticize the builders of the models, but omissions from a model should not imply omissions from an argument. We must carefully assess how these models may mislead.

Many scientists are telling us that our economic models grossly underestimate the risks. In these circumstances, it is irresponsible to act as if the economic models currently dominating policy analysis represent a sensible central case. They do not: they generally grossly underestimate risk, the social cost of carbon, the necessary urgency in climate action, and the potential attractiveness and discovery of the alternative low-carbon pathways.

Why Are We Waiting?

The Logic, Urgency, and Promise of Tackling Climate Change

By: Nicholas Stern

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