

2 Economics, Ethics and Climate Change

Key Messages

Climate change is a result of the externality associated with greenhouse-gas emissions – it entails costs that are not paid for by those who create the emissions.

It has a number of features that together distinguish it from other externalities:

- It is **global** in its causes and consequences;
- The impacts of climate change are **long-term and persistent**;
- **Uncertainties and risks** in the economic impacts are pervasive.
- There is a serious risk of major, irreversible change with **non-marginal economic effects**.

These features shape the economic analysis: it must be **global**, deal with **long** time horizons, have the economics of **risk and uncertainty** at its core, and examine the possibility of major, **non-marginal** changes.

The **impacts of climate change are very broad ranging and interact with other market failures and economic dynamics, giving rise to many complex policy problems**. Ideas and techniques from most of the important areas of economics have to be deployed to analyse them, including many recent advances.

The breadth, magnitude and nature of impacts imply that several ethical perspectives, such as those focusing on welfare, equity and justice, freedoms and rights, are relevant. Most of these perspectives imply that the outcomes of climate-change policy are to be understood in terms of impacts on consumption, health, education and the environment over time but different ethical perspectives may point to different policy recommendations.

Questions of intra- and inter-generational equity are central. Climate change will have serious impacts within the lifetime of most of those alive today. Future generations will be even more strongly affected, yet they lack representation in present-day decisions.

Standard externality and cost-benefit approaches have their usefulness for analysing climate change, but, as they are methods focused on evaluating marginal changes, and generally abstract from dynamics and risk, they can only be starting points for further work.

Standard treatments of discounting are valuable for analysing marginal projects but are inappropriate for non-marginal comparisons of paths; the approach to discounting must meet the challenge of assessing and comparing paths that have very different trajectories and involve very long-term and large inter-generational impacts. We must go back to the first principles from which the standard marginal results are derived.

The severity of the likely consequences and the application of the above analytical approaches form the basis of powerful arguments, developed in the Review, in favour of strong and urgent global action to reduce greenhouse-gas emissions, and of major action to adapt to the consequences that now cannot be avoided.

2.1 Introduction

The science described in the previous chapter drives the economics that is required for the analysis of policy. This chapter introduces the conceptual frameworks that we will use to examine the economics of climate change. It explores, in Section 2.2, the distinctive features of the externalities associated with greenhouse-gas emissions and draws attention to some of the difficulties associated with a simplistic application of the standard theory of externalities to this problem. Section 2.3 introduces a variety of ethical approaches and relates them to the

global and long-term nature of the impacts (the discussion is extended in the appendix to the chapter). Section 2.4 examines some specifics of intertemporal allocation, including discounting (some further technical details are provided in the appendix to the chapter). Sections 2.5 and 2.6 consider how economic analysis can get to grips with a problem that is uncertain and involves a serious risk of large losses of wellbeing, due to deaths, extinctions of species and heavy economic costs, rather than the marginal changes more commonly considered in economics. For most of economic policy, the underlying ethical assumptions are of great importance, and this applies particularly for climate change: that is why they are given special attention in this chapter.

The economics introduced in this chapter applies, in principle, to the whole Review but the analysis of Sections 2.2 to 2.6 is of special relevance to Parts II and III, which look at impacts and at the economics of mitigation – assessing how much action is necessary to reduce greenhouse-gas emissions. Parts IV, V, VI of this report are devoted to the analysis of policy to promote mitigation and adaptation. The detailed, and often difficult, economics of public policy and collective action that are involved in these analyses are introduced in the sections themselves and we provided only brief coverage in Sections 2.7 and 2.8. In the former section, we refer briefly to the modern public economics of carbon taxation, trading and regulation and of the promotion of research, development and deployment, including the problems of various forms of market imperfection affecting innovation. It also covers an analysis of the role of ‘responsible behaviour’ and how public understanding of this notion might be influenced by public policy. Section 2.8 explores some of the difficulties of building and sustaining global collective action in response to the global challenge of climate change.

In these ways, this chapter lays the analytical foundations for much of the economics required by the challenge of climate change and which is put to work in the course of the analysis presented in this Review.

The subject demands analysis across an enormous range of issues and requires all the tools of economics we can muster – and indeed some we wish we had. In setting out some of these tools, some of the economic analysis of this chapter is inevitably technical, even though the more mathematical material has been banished to an appendix. Some readers less interested in the technical underpinnings of the analysis may wish to skim the more formal analytical material. Nevertheless, it is important to set out some of the analytical instruments at the beginning of the Review, since they underpin the analysis of risk, equity and allocation over time that must lie at the heart of a serious analysis of the economics of climate change.

2.2 Understanding the market failures that lead to climate change

Climate change results from greenhouse-gas emissions associated with economic activities including energy, industry, transport and land use.

In common with many other environmental problems, human-induced climate change is at its most basic level an externality. Those who produce greenhouse-gas emissions are bringing about climate change, thereby imposing costs on the world and on future generations, but they do not face directly, neither via markets nor in other ways, the full consequences of the costs of their actions.

Much economic activity involves the emission of greenhouse gases (GHGs). As GHGs accumulate in the atmosphere, temperatures increase, and the climatic changes that result impose costs (and some benefits) on society. However, the full costs of GHG emissions, in terms of climate change, are not immediately – indeed they are unlikely ever to be – borne by the emitter, so they face little or no economic incentive to reduce emissions. Similarly, emitters do not have to compensate those who lose out because of climate change.¹ In this sense, human-induced climate change is an externality, one that is not ‘corrected’ through any institution or market,² unless policy intervenes.

¹ Symmetrically, those who benefit from climate change do not have to *reward* emitters.

² Pigou (1912).

The climate is a public good: those who fail to pay for it cannot be excluded from enjoying its benefits and one person's enjoyment of the climate does not diminish the capacity of others to enjoy it too.³ Markets do not automatically provide the right type and quantity of public goods, because in the absence of public policy there are limited or no returns to private investors for doing so: in this case, markets for relevant goods and services (energy, land use, innovation, etc) do not reflect the consequences of different consumption and investment choices for the climate. Thus, climate change is an example of market failure involving externalities and public goods.⁴ Given the magnitude and nature of the effects initially described in the previous chapter and taken forward in Parts II and III, it has profound implications for economic growth and development. All in all, it must be regarded as market failure on the greatest scale the world has seen.

The basic theory of externalities and public goods is the starting point for most economic analyses of climate change and this Review is no exception. The starting point embodies the basic insights of Pigou, Meade, Samuelson and Coase (see Part IV). But the special features of this particular externality demand, as we shall see, that the economic analysis go much further.

The science of climate change means that this is a very different form of externality from the types commonly analysed.

Climate change has special features that, together, pose particular challenges for the standard economic theory of externalities. There are four distinct issues that will be considered in turn in the sections below.

- Climate change is an externality that is global in both its causes and consequences. The incremental impact of a tonne of GHG on climate change is independent of where in the world it is emitted (unlike other negative impacts such as air pollution and its cost to public health), because GHGs diffuse in the atmosphere and because local climatic changes depend on the global climate system. While different countries produce different volumes the marginal damage of an extra unit is independent of whether it comes from the UK or Australia.
- The impacts of climate change are persistent and develop over time. Once in the atmosphere, some GHGs stay there for hundreds of years. Furthermore, the climate system is slow to respond to increases in atmospheric GHG concentrations and there are yet more lags in the environmental, economic and social response to climate change. The effects of GHGs are being experienced now and will continue to work their way through in the very long term.
- The uncertainties are considerable, both about the potential size, type and timing of impacts and about the costs of combating climate change; hence the framework used must be able to handle risk and uncertainty.
- The impacts are likely to have a significant effect on the global economy if action is not taken to prevent climate change, so the analysis has to consider potentially non-marginal changes to societies, not merely small changes amenable to ordinary project appraisal.

These features shape much of the detailed economic analysis throughout this Review. We illustrate with just one example, an important one, which shows how the dynamic nature of the accumulation of GHGs over time affects one of the standard analytical workhorses of the economics of externalities and the environment. It is common to present policy towards climate change in terms of the social cost of carbon on the margin (SCC) and the marginal abatement (MAC). The former is the total damage from now into the indefinite future of emitting an extra unit of GHGs now – the science says that GHGs (particularly CO₂) stay in the atmosphere for a very long time. Thus, in its simplest form, the nature of the problem is that the stock of gases in the atmosphere increases with the net flow of GHGs emissions in this period, and thus decreases with abatement. Therefore, on the one hand, the SCC curve

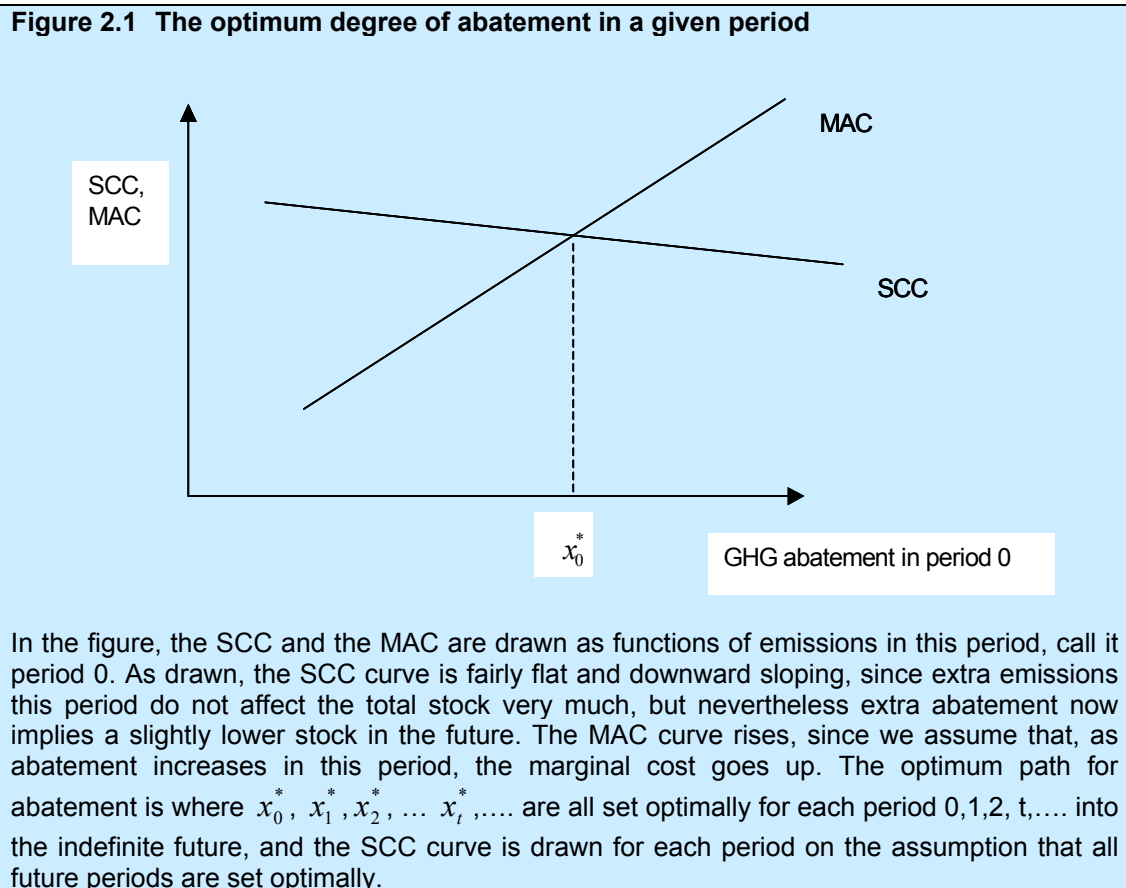
³ Samuelson (1954).

⁴ Formally, in economic theory, public goods are a special case of externalities where the effects of the latter are independent of the identity of the emitters or origin of the externalities.

slopes downwards with increasing abatement in any given period, assuming that the lower the stock at any point in the future, the less the marginal damage. On the other hand, the MAC curve slopes upwards with increasing abatement, if it is more costly on the margin to do more abatement as abatement increases in the given period. The optimum level of abatement must satisfy the condition that MAC equals SCC. If, for example, SCC were bigger than MAC, the social gain from one extra unit of abatement would be less than the cost and it would be better to do a little more. We call the optimum level this period x_0^* .

It should be clear that the SCC curve this period depends on future emissions: if we revised upwards our specified assumptions on future emissions, the whole SCC curve would shift upwards, and so would the optimum abatement level in this period, x_0^* . Thus, if we are thinking about an optimum path over time, rather than simply an optimum emission for this period, we must recognise that the SCC curve for any given period depends on the future stock and thus on the future path of emissions. **We cannot sensibly calculate an SCC without assuming that future emissions and stocks follow some specified path. For different specified paths, the SCC will be different.** For example, it will be much higher on a ‘business as usual’ path (BAU) than it will be on a path that cuts emissions strongly and eventually stabilises concentrations. It is remarkable how often SCC calculations are vague on this crucial point (see Chapter 13 for a further discussion).

Thus we must be very careful how we use a diagram that is pervasive in the economics of climate change – see Figure 2.1.

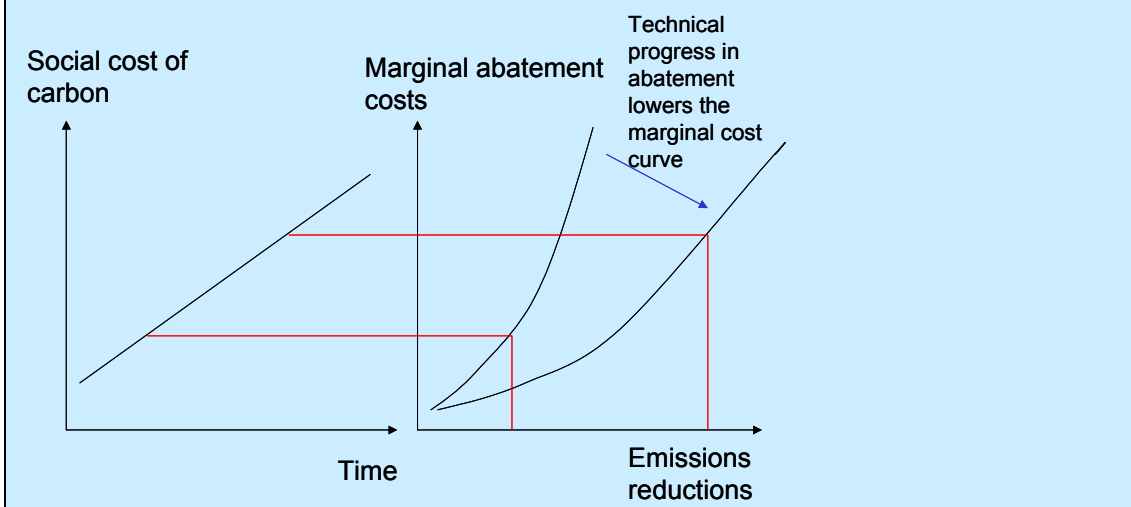


A number of important points follow from this, in addition to the basic one that an SCC curve cannot be drawn, nor an SCC calculated, without specific assumptions on future paths. First, if the SCC rises over time along the specified path then, for optimality, so too must the MAC. It is very likely that the SCC *will* rise over time, since stocks of GHGs will rise as further emissions take place, up to the point where stabilisation is reached. Thus the MAC at the optimum rises and the intersection of the MAC and SCC curves will imply successively

greater abatement. This is true even though the whole MAC curve is likely to be lower for any particular degree of abatement in the future because learning will have taken place.

Figure 2.2 is thus perhaps more helpful than Figure 2.1 in sketching the nature of the solution to the problem. The position of the schedule in the left-hand side panel depends on the stabilisation target chosen for the atmospheric concentration of greenhouse gases, which in turn depends upon how the expected present values (in terms of discounted utility) of costs and benefits of mitigation through time change as the stabilisation level changes. Hence the choice of stabilisation target implies a view about what is likely to happen to abatement costs over time. The right-hand panel shows the shifts in the MAC curve expected at the time the stabilisation target is chosen.

Figure 2.2 How the path for the social cost of carbon drives the extent of abatement



This illustrates how important it is that the dynamics of the problem are considered. The conclusion that the MAC rises along an optimum path does not automatically follow from an analysis that simply shifts the SCC curve upwards over time (with higher stocks) and shifts the MAC down over time (with learning), without linking to the full dynamic optimisation. That optimisation takes account of the known future fall in costs in determining the whole path for the SCC. We are simply assuming that this fall in costs could not be of a magnitude to make it optimum for stocks to fall, that is, for emissions to be less than the Earth system's equilibrium capacity to absorb greenhouse gases from the atmosphere.

This analysis raises the second point, about the role of uncertainty. In the above argument, there is no consideration of uncertainty. If that vital element is now introduced, the argument becomes more complex. It has to be asked whether the resolution of uncertainty in any period would lead to a revision of views about the future probability distributions for abatement costs and climate-change damages. If, for example, there is unexpected good news that abatement is likely to be much cheaper than previously thought, then a lower stabilisation target and more abatement over time than originally planned would become appropriate. This would reduce the SCC from where it would otherwise have been. However, one surprisingly good period for costs does not necessarily imply that future periods will be just as good. In Figure 2.2, persistently faster technical progress than expected (as opposed to random fluctuations of the MAC around its expected value) would lead to a downward revision of the stabilisation target and hence a downward shift in the schedule in the left-hand panel.

Dynamics and uncertainty are explored further in Chapters 13 and 14, while analyses involving risk are taken further in Sections 2.5 and 2.6 and in Chapter 6.

This important example shows how important it is to integrate the scientific features of the externality into the economics and shows further that there are difficult conceptual and technical questions to be tackled. The analysis must cover a very broad range, including the

economics of: growth and development; industry; innovation and technological change; institutions; the international economy; demography and migration; public finance; information and uncertainty; and the economics of risk and equity; and environmental and public economics throughout.

2.3 Ethics, welfare and economic policy

The special features of the climate-change externality pose difficult questions for the standard welfare-economic approach to policy.

Chapter 1 shows that the effects of climate change are global, intertemporal and highly inequitable. The inequity of climate change is examined further in Part II.. Generally, poor countries, and poor people in any given country, suffer the most, notwithstanding that the rich countries are responsible for the bulk of past emissions. These features of climate change, together with the fact that they have an impact on many dimensions of human well-being, force us to look carefully at the underlying ethical judgements and presumptions which underpin, often implicitly, the standard framework of policy analysis. Indeed, it is important to consider a broader range of ethical arguments and frameworks than is standard in economics, both because there are many ways of looking at the ethics of policy towards climate change, and, also, because in so doing we can learn something about how to apply the more standard economic approach. There is a growing literature on the ethics of climate change: analysis of policy cannot avoid grappling directly with the difficult issues that arise. These ethical frameworks are discussed more formally in the technical appendix to this chapter; the discussion here is only summary⁵.

The underlying ethics of basic welfare economics, which underpins much of the standard analysis of public policy, focuses on the consequences of policy for the consumption of goods and services by individuals in a community. These goods and services are generated by labour, past saving, knowledge and natural resources. The perspective sees individuals as having utility, or welfare, arising from this consumption.

In this approach, the objective is to work out the policies that would be set by a decision-maker acting on behalf of the community and whose role it is to improve, or maximise, overall social welfare. This social welfare depends on the welfare of each individual in the community. When goods and services are defined in a broad way, they can include, for example, education, health and goods appearing at different dates and in different circumstances. Thus the theory covers time and uncertainty. And, to the extent that individuals value the environment, that too is part of the analysis. Many goods or services, including education, health and the environment, perform a dual role: individuals directly value them and they are inputs into the use or acquisition of other consumption goods. In the jargon, they are both goals and instruments.

The standard economic theory then focuses on flows of goods or services over time and their distribution across individuals. The list of goods or services should include consumption (usually monetary or the equivalent), education, health and the environment. These are usually the areas focused upon in cross-country comparisons of living standards, such as, for example, in the *World Development Indicators* of the World Bank, the *Human Development Report* of the UNDP, and the *Millennium Development Goals* (MDGs) agreed at the UN at the turn of the millennium. 'Stocks' of wealth, infrastructure, the natural environment and so on enter into the analysis in terms of their influence on flows. Through these choices of data for central attention and through the choice of goals, the international community has identified a strong and shared view on the key dimensions of human well-being.

Those choices of data and goals can be derived from a number of different ethical perspectives (see, for example, Sen (1999)). Most ethical frameworks generally used in the analyses of economic policy have some relevance for the economics of climate change and

⁵ Particularly important contributions on ethics are those of Beckerman and Pasek (2001), Broome (1992, 1994, 2004, 2005), Gardiner (2004) and Müller (2006). We are very grateful to John Broome for his advice and guidance, but he is not responsible for the views expressed here.

there are some – for example, those involving stewardship and sustainability – that are particularly focused on environmental issues.

The ethical framework of standard welfare economics looks first only at the consequences of actions (an approach often described as ‘consequentialism’) and then assesses consequences in terms of impacts on ‘utility’ (an approach often described as ‘welfarism’, as in Sen (1999), Chapter 3 and the appendix to this chapter). This standard welfare-economic approach has no room, for example, for ethical dimensions concerning the processes by which outcomes are reached. Some different notions of ethics, including those based on concepts of rights, justice and freedoms, do consider process. Others, such as sustainability, and stewardship, emphasise particular aspects of the consequences of decisions for others and for the future, as explained in the technical appendix.

Nevertheless, the consequences on which most of these notions would focus for each generation often have strong similarities: above all, with respect to the attention they pay to consumption, education, health and the environment.

And all the perspectives would take into account the distribution of outcomes within and across generations, together with the risks involved in different actions, now and over time. Hence the Review focuses on the implications of action or inaction on climate change for these four dimensions.

How the implications for these four dimensions are assessed, will, of course, vary according to the ethical position adopted. How policy-makers aggregate over consequences (i) within generations, (ii) over time, and (iii) according to risk will be crucial to policy design and choice. Aggregation requires being quantitative in comparing consequences of different kinds and for different people. The Review pays special attention to all three forms of aggregation. In arriving at decisions, or a view, it is not, however, always necessary to derive a single number that gives full quantitative content and appropriate weight to all the dimensions and elements involved (see below).

Climate change is an externality that is global in both its causes and consequences. Both involve deep inequalities that are relevant for policy.

The incremental impact of a tonne of GHG is independent of where in the world it is emitted. But the volume of GHGs emitted globally is not uniform. Historically, rich countries have produced the majority of GHG emissions. Though all countries are affected by climate change, they are affected in different ways and to different extents. Developing countries will be particularly badly hit, for three reasons: their geography; their stronger dependence on agriculture; and because with their fewer resources comes greater vulnerability. There is therefore a double inequity in climate change: the rich countries have special responsibility for where the world is now, and thus for the consequences which flow from this difficult starting point, whereas poor countries will be particularly badly hit.

The standard welfare-economics framework has a single criterion, and implicitly, a single governmental decision-maker. It can be useful in providing a benchmark for what a ‘good’ global policy would look like. But the global nature of climate change implies that the simple economic theory with one jurisdiction, one decision-maker, and one social welfare function cannot be taken literally. Instead, it is necessary to model how different players or countries will interact (see Section 2.8 below and Pt VI) and to ask ethical questions about how people in one country or region should react to the impacts of their actions on those in another. This raises questions of how the welfare of people with very different standards of living should be assessed and combined in forming judgements on policy.

There are particular challenges in valuing social welfare across countries at different stages of development and across different income or consumption levels.

The ethical question of how consequences for people in very different circumstances should be aggregated must be faced directly. For the sake of simplicity and clarity, we shall adopt the perspective of the ‘social welfare function’ approach, as explained in Box 2.1.

Box 2.1 The ‘social welfare function’ approach to ‘adding up’ the wellbeing of different people.

The stripped-down approach that we shall adopt when we attempt to assess the potential costs of climate change uses the standard framework of welfare economics. The objective of policy is taken to be the maximisation of the sum across individuals of social utilities of consumption. Thus, in this framework, aggregation of impacts across individuals using social value judgements is assumed to be possible. In particular, we consider consumption as involving a broad range of goods and services that includes education, health and the environment. The relationship between the measure of social wellbeing – the sum of social utilities in this argument – and the goods and services consumed by each household, on which it depends, is called the social welfare function.

In drawing up a social welfare function, we have to make explicit value judgements about the distribution of consumption across individuals – how much difference should it make, for example, if a given loss of consumption opportunities affects a rich person rather than a poor person, or someone today rather than in a hundred years’ time?⁶ Aggregating social utility across individuals to come up with a measure of social welfare has its problems. Different value judgements can lead to different rankings of possible outcomes, and deciding what values should be applied is difficult in democratic societies⁷. It is not always consistent with ethical perspectives based on rights and freedoms. But the approach has the virtue of clarity and simplicity, making it easy to test the sensitivity of the policy choice that emerges to the value judgements made. It is fairly standard in the economics of applied policy problems and allows for a consistent treatment of aggregation within and across generations and for uncertainty. The social welfare function’s treatment of income differences can be calibrated by simple thought experiments. For example, suppose the decision-maker is considering two possible policy outcomes. In the second outcome, a poor person receives an income \$X more than in the first, but a rich person receives \$Y less; how much bigger than X would Y have to be for the decision-maker to decide that the second outcome is worse than the first?

Aggregation across education, health, income and environment raises profound difficulties, particularly when comparisons are made across individuals. Some common currency or ‘numeraire’ is necessary: the most common way of expressing an aggregate measure of wellbeing is in terms of real income. That immediately raises the challenge of expressing health (including mortality) and environmental quality in terms of income. There have been many attempts to do just that. These should not be lightly dismissed, since nations often decide how much to allocate to, for example, accident and emergency services or environmental protection in the knowledge that a little extra money saves lives and improves the environment. Indeed, individuals make similar choices in their own lives.

Nevertheless, there are significant difficulties inherent in the valuation of health and the environment, many of which are magnified across countries where major differences in income affect individuals’ willingness and ability to pay for them. For example, a very poor person may not be ‘willing-to-pay’ very much money to insure her life, whereas a rich person may be prepared to pay a very large sum. Can it be right to conclude that a poor person’s life

⁶Effectively, in putting it this way, we resist the interpretation that this is a strict utilitarian sum of ‘actual utility’. On some of the difficulties and attractions of consequentialism, welfarism, utilitarianism and other approaches, see e.g. Sen and Williams (1982) and Sen (1999).

⁷The difficulties of this type of aggregation using democratic methods have been examined by Kenneth Arrow (1951, 1963) using his famous ‘impossibility theorem’. It has been examined in a series of studies by Amartya Sen (see, for example, Sen (1970, 1986 and 1999)).

or health is therefore less valuable?⁸ It is surely within the realms of sensible discourse to think of the consequences of different strategies simultaneously in terms of income, lives and the environment: that is the approach we adopt where possible. At some points (such as in Chapter 6), however, we present models from the literature that do embody estimates of the monetary equivalent of the impacts of climate change on broader dimensions of welfare (although generally in these contexts increments in income are valued differently at different levels in income – see Box 2.1). Such exercises should be viewed with some circumspection.

2.4 The long-run impacts of climate change: evaluation over time and discounting

The effects of GHGs emitted today will be felt for a very long time. That makes some form of evaluation or aggregation across generations unavoidable. The ethical decisions on, and approaches to, this issue have major consequences for the assessment of policy.

The approach we adopt here is similar to that for assessing impacts that fall on different people or nations, and in some respects continues the discussion of ethics in the preceding section. When we do this formally, we work in terms of sums of utilities of consumption. Again there is a problem of calibrating the social welfare function for this purpose but, as with aggregating across people with different incomes at a moment in time, one can use a series of ‘thought experiments’ to help (see Box 2.1).

Typically, in the application of the theory of welfare economics to project and policy appraisal, an increment in future consumption is held to be worth less than an increment in present consumption, for two reasons. First, if consumption grows, people are better off in the future than they are now and an extra unit of consumption is generally taken to be worth less, the richer people are. Second, it is sometimes suggested that people prefer to have good things earlier rather than later – ‘pure time preference’ – based presumably in some part on an assessment of the chances of being alive to enjoy consumption later and in some part ‘impatience’.

Yet assessing impacts over a very long time period emphasises the problem that future generations are not fully represented in current discussion. Thus we have to ask how they should be represented in the views and decisions of current generations. This throws the second rationale for ‘discounting’ future consumption mentioned above – pure time preference – into question. We take a simple approach in this Review: if a future generation will be present, we suppose that it has the same claim on our ethical attention as the current one.

Thus, while we do allow, for example, for the possibility that, say, a meteorite might obliterate the world, and for the possibility that future generations might be richer (or poorer), we treat the *welfare* of future generations on a par with our own. It is, of course, possible that people actually do place less value on the welfare of future generations, simply on the grounds that they are more distant in time. But it is hard to see any ethical justification for this. It raises logical difficulties, too. The discussion of the issue of pure time preference has a long and distinguished history in economics, particularly among those economists with a strong interest and involvement in philosophy⁹. It has produced some powerful assertions. Ramsey (1928, p.543) described pure time discounting as ‘ethically indefensible and [arising] merely from the weakness of the imagination’. Pigou (1932, pp 24-25) referred to it as implying that ‘our telescopic faculty is defective’. Harrod (1948, pp 37-40) described it as a ‘human infirmity’ and ‘a polite expression for rapacity and the conquest of reason by passion’. Solow (1974, p.9) said ‘we ought to act as if the social rate of time preference were zero (though we would simultaneously discount future *consumption* if we expected the future to be richer than the

⁸ Notice however that if the valuation of life in money terms in country A is twice that of country B, where income in A is twice that in B, we may choose to value increases in income in A half as much as for B (see Box 2.1 and Chapter 6). In that case, extra mortality would be valued in the way for both countries.

⁹ See Anand and Sen (2000) for a technical discussion of these issues, and further references and quotes beyond those here. And see Broome (1991) and (2004) for an extended discussion. We are grateful to Sudhir Anand and John Broome for discussions of these issues.

present)'. Anand and Sen (2000) take a similar view. The appendix to this chapter explores these issues in more technical detail, and includes references to one or two dissenting views.

However, we must emphasise that the approach we adopt, aggregating utility of consumption, does take directly into account the possibility that future generations may be richer or poorer, the first rationale for discounting above. Uncertainty about future prospects plays an important role in the analysis of the Review. How well off we may be when a cost or benefit arrives does matter to its evaluation, as does the probability of the occurrence of costs and benefits. Those issues, *per se*, are not reasons for discounting (other than the case of uncertainty about existence).

A formal discussion of discounting inevitably becomes mathematically technical, as one must be explicit about growth paths and intertemporal allocations. The simple techniques of comparing future incomes or consumption with those occurring now using discount rates (other than for 'pure time preference') is not valid for comparing across paths that are very different. Further, where comparisons are for marginal decisions and the use of discount rates is valid, then, for a number of reasons, particularly uncertainty, discount rates may fall over time. A formal discussion is provided in the appendix to this chapter: the results are summarised in Box 2.2.

Box 2.2 Discounting

Discounting, as generally used in economics, is a technique relevant for marginal perturbations around a given growth path. A discount rate that is common across projects can be used only for assessing projects that involve perturbations around a path and not for comparing across very different paths.

With marginal perturbations, the key concept is the discount factor: the value of an increment in consumption at a time in the future relative to now. The discount factor will generally depend on the consumption level in the future relative to that now, i.e. on growth, and on the social utility or welfare function used to evaluate consumption (see Box 2.1).

The discount rate is the rate of fall of the discount factor. There is no presumption that it is constant over time, as it depends on the way in which consumption grows over time.

- If consumption falls along a path, the discount rate can be negative.
- If inequality rises over time, this would work to reduce the discount rate, for the social welfare functions typically used.
- If uncertainty rises as outcomes further into the future are contemplated, this would work to reduce the discount rate, with the welfare functions typically used. Quantification of this effect requires specification of the form of uncertainty, and how it changes, and of the utility function.

With many goods and many households, there will be many discount rates. For example, if conventional consumption is growing but the environment is deteriorating, then the discount rate for consumption would be positive but for the environment it would be negative. Similarly, if the consumption of one group is rising but another is falling, the discount rate would be positive for the former but negative for the latter.

Taking the analysis of this section and that of the appendix to this chapter together with the discussion of ethics earlier in this chapter, it can be seen that the standard welfare framework is highly relevant as a theoretical basis for assessing strategies and projects in the context of climate change. However, the implications of that theory are very different from those of the techniques often used in cost-benefit analysis. For example, a single constant discount rate would generally be unacceptable for dealing with the long-run, global, non-marginal impacts of climate change.

For further discussion of discounting, and references to the relevant literature, see the technical annex to this chapter.

This approach to discounting and the ethics from which it is derived is of great importance for the analysis of climate change. That is why we have devoted space to it at the beginning of our Review. **If little or no value were placed on prospects for the long-run future, then climate change would be seen as much less of a problem. If, however, one thinks about the ethics in terms of most standard ethical frameworks, there is every reason to take these prospects very seriously.**

2.5 Risk and Uncertainty

The risks and uncertainties around the costs and benefits of climate policy are large; hence the analytical framework should be able to handle risk and uncertainty explicitly.

For the moment, we do not make a distinction between risk and uncertainty, but the distinction is important and we return to it below. Uncertainty affects every link in the chain from emissions of GHGs through to their impacts. There are uncertainties associated, for example, with future rates of economic growth, with the volume of emissions that will follow, with the increases in temperature resulting from emissions, with the impacts of these temperature increases and so on. Similarly, there are uncertainties associated with the economic response to policy measures, and hence about how much it will cost to reduce GHG emissions.

Our treatment of uncertainty follows a similar approach to that for evaluation or aggregation over space and time. Where we embody uncertainty formally in our models, we add utilities over possible states of the world that might result from climate change, weighting by the probability of those states. This yields what is known as ‘expected’ utility.

This is essentially the extension of the social utility approach to an uncertain or ‘stochastic’ environment. As in a certain or ‘deterministic’ environment, it has its ethical difficulties, but it has the virtues of transparency, clarity, and consistency. Again, it is fairly standard in applied economics.

The basis of such probabilities should be up-to-date knowledge from science and economics. This amounts to a ‘subjective’ probability approach.¹⁰ It is a pragmatic response to the fact that many of the ‘true’ uncertainties around climate-change policy cannot themselves be observed and quantified precisely, as they can be in many engineering problems, for example.

The standard expected-utility framework involves aversion to risk and in this narrow sense a ‘precautionary principle’.

This approach to uncertainty, combined with the assumption that the social marginal utility of income declines as income rises, implies that society will be willing to pay a premium (insurance) to avoid a simple actuarially fair gamble where potential losses and gains are large. As Parts II and III show, potential losses from climate change are large and the costs of avoidance (the insurance premium involved in mitigation), we argue, seem modest by comparison.

The analytical approach incorporates aspects of insurance, caution and precaution directly, and does not therefore require a separate ‘precautionary principle’ to be imposed as an extra ethical criterion.

More modern theories embodying a distinction between uncertainty and risk suggest an explicit ‘precautionary principle’ beyond that following from standard expected-utility theory.

The distinction between uncertainty and risk is an old one, going back at least to Knight (1921) and Keynes (1921). In their analysis, risk applied when one could make some

¹⁰ Often called a ‘Bayesian’ approach, after Thomas Bayes, the 18th century mathematician. However, the application of Bayes’ ideas to a subjective theory of probability was made in the 20th century. See Ramsey (1931).

assessment of probabilities and uncertainty when one does not have the ability to assess probabilities. In a fascinating paper, Claude Henry (2006) puts these ideas to work on problems in science and links them to modern theories of behaviour towards risk. He uses two important examples to illustrate the relevance of a precautionary principle in the presence of uncertainty. The first is the link between bovine spongiform encephalopathy (BSE) in cows and Creutzfeldt-Jacob Disease (CJD) in humans and the second, the link between asbestos and lung disease.

For the first, UK scientists asserted for some time that there could be no link because of ‘a barrier between species’. However in 1991 scientists in Bristol succeeded in inoculating a cat with BSE and the hypothesis of ‘a barrier’ was destroyed. Around the same time, a scientist, Stanley Prusiner, identified protein mutations that could form the basis of a link. These results did not establish probabilities but they destroyed ‘certainty’. By introducing uncertainty, the finding opened up the possibility of applying a precautionary principle.

For the second, a possible link between asbestos and lung disease was suggested as early as 1898 by health inspectors in the UK, and in 1911 on a more scientific basis after experiments on rats. Again the work was not of a kind to establish probabilities but provided grounds for precaution. Unfortunately, industry lobbying prevented a ban on asbestos and the delay of fifty years led to considerable loss of life. Application of the precautionary principle could have saved lives.

Henry refers to recent work by Maccheroni et al (2005) and Klibanoff et al (2005) that formalises this type of argument,¹¹ giving, in effect, a formal description of the precautionary principle. In this formalisation, there are a number of possible probability distributions over outcomes that could follow from some action. But the decision-maker, who is trying to choose which action to take, does not know which of these distributions is more or less likely for any given action. It can be shown under formal but reasonable assumptions¹² that she would act as if she chooses the action that maximises a weighted average of the worst expected utility and the best expected utility, where best and worst are calculated by comparing expected utilities using the different probability distributions. The weight placed on the worst outcome would be influenced by concern of the individual about the magnitude of associated threats, or pessimism, and possibly any hunch about which probability might be more or less plausible. It is an explicit embodiment of ‘aversion to uncertainty’, sometimes called ‘aversion to ambiguity’, and is an expression of the ‘precautionary principle’. It is different from and additional to the idea of ‘aversion to risk’ associated with and derived from expected utility.

The ability to work with probability distributions in the analysis of climate change was demonstrated in Chapter 1. But there is genuine uncertainty over which of these distributions should apply. In particular, the science and economics are particularly sparse precisely where the stakes are highest – at the high temperatures we now know may be possible. Uncertainty over probability distributions is precisely the situation we confront in the modelling of Chapter 6. As Claude Henry puts it in the conclusion to his 2006 paper, ‘uncertainty should not be inflated and invoked as an alibi for inaction’. We now have a theory that can describe how to act.

2.6 Non-marginal policy decisions

There is a serious risk that, without action to prevent climate change, its impacts will be large relative to the global economy, much more so than for most other environmental problems.

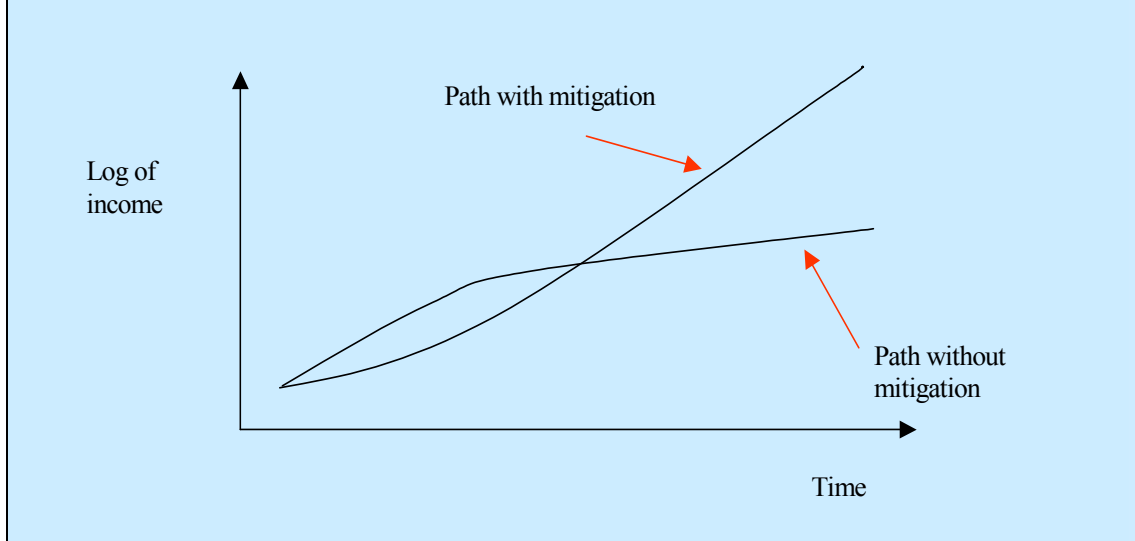
The impacts of climate change on economies and societies worldwide could be large relative to the global economy. Specifically, it cannot be assumed that the global economy, net of the costs of climate change, will grow at a certain rate in the future, regardless of whether nations

¹¹ See also Chichilnisky (2000)

¹² Essentially the axioms are similar to those of the standard Von Neumann-Morgenstern theorem deriving expected utility except the dependence axiom is relaxed slightly. See Gollier (2001), for example, for a description of the Von Neumann-Morgenstern approach.

follow a ‘business as usual’ path or choose together to reduce GHG emissions. In this sense, the decision is not a marginal one.

Figure 2.3 Conceptual approach to comparing divergent growth paths over the long-term



The issues are represented schematically in Figure 2.4, which compares two paths, one with mitigation and one without. We should note that, in this diagram, there is uncertainty around each path, which should be analysed using the approaches of the preceding section. This is crucial to the analysis in much of the Review. Income on the ‘path with mitigation’ is below that on the path without (‘business as usual’) for the earlier time period, because costs of mitigation are incurred. Later, as the damages from climate change accumulate, growth on the ‘path without mitigation’ will slow and income will fall below the level on the other path. The analysis of Part III attempts to quantify these effects and finds that the ‘greener’ path (with mitigation) allows growth to continue but, on the path without mitigation, income will suffer. The analysis requires formal comparison between paths and Part III shows that the losses from mitigation in the near future are strongly outweighed by the later gains in averted damage.

2.7 The public policy of promoting mitigation

Having established the importance of strong mitigation in Parts II and III of the Review, Part IV is devoted to policy to bring it about. The basic theory of externalities identifies the source of the economic problem in untaxed or unpriced emissions of GHGs.

The externality requires a price for emissions: that is the first task of mitigation policy.

The first task of policy is therefore to introduce taxes or prices for GHGs. The Pigou treatment of externalities points to taxes based on the marginal damages caused by carbon emissions. In the diagram shown in Figure 2.1, the appropriate tax would be equal to the social cost of carbon at the point where it is equal to the marginal abatement cost. Faced with this tax, the emitters would choose the appropriate level of abatement.

However, the modern theory of risk indicates that long-term quantity targets may be the right direction for policy, with trading within those targets or regular revision of taxes to keep on course towards the long-run objective (see Chapter 14). Given the long-run nature of many of the relevant decisions, whichever policies are chosen, credibility and predictability of policy will be crucial to effectiveness.

The second task of mitigation policy is to promote research, development and deployment.

However, the inevitable absence of total credibility for GHG pricing policy decades into the future may inhibit investment in emission reduction, particularly the development of new technologies. Action on climate change requires urgency, and there are generally obstacles, due to inadequate property rights, preventing investors reaping the full return to new ideas. Specifically, there are spillovers in learning (another externality), associated with the development and adoption of new low-emission technologies that can affect how much emissions are reduced. Thus the economics of mitigating climate change involves understanding the processes of innovation.

The spillovers occur in a number of ways. A firm is unlikely to be able to appropriate all the benefits, largely because knowledge has some characteristics of a public good. In particular, once new information has been created, it can be virtually costless to copy. This allows a competitor with access to the information to capture the benefits without undertaking the research and development (R&D). Patents are commonly used to reduce this problem. In addition, there are typically 'adoptive externalities' to other firms that arise from the processes whereby technology costs fall as a result of increasing adoption. These spillovers are likely to be particularly important in the case of low-emission technologies that can help to mitigate climate change, as Chapter 16 explains.

Other interacting barriers or problem that are relevant include

- asymmetric and inadequate information – for example, about energy-efficiency measures
- policy-induced uncertainties – such as uncertainty about the implicit price of carbon in the future
- moral hazard or 'gaming' – for example firms might rush to make carbon-emitting investments to avoid the possibility of more stringent regulation in the future
- perverse regulatory incentives – such as the incentive to establish a high baseline of emissions in regimes where carbon quotas are 'grandfathered'
- the endogenous price dynamics of exhaustible natural resources – and the risk that fossil-fuel prices could fall in response to strong climate-change policy, threatening to undermine it.¹³

These issues involve many of the most interesting theoretical questions studied by economists in recent years in industrial, regulatory and natural resource economics.

There are important challenges for public policy to promote mitigation beyond the two tasks just described. That is the subject of Chapter 16. These include regulation and standards and deepening public understanding of responsible behaviour.

Standards and regulation can provide powerful and effective policies to promote action on mitigation.

The learning process for new technologies is uncertain. There are probably important scale effects in this process due to experience or learning-by-doing and the externalities of learning-by-watching. In these circumstances, standards for emissions, for example, can provide a clear sense of direction and reduced uncertainty for investors, allowing these economies of scale to be realised.

In other circumstances, particularly concerning energy efficiency, there will be market imperfections, for example due to the nature of landlord-tenant relations in property, that may inhibit adaptation of beneficial investments or technologies. In these circumstances, regulation can produce results more efficient than those that are available from other instruments alone.

¹³ The economic theory of exhaustible natural resources is expounded by Dasgupta and Heal (1979). A seminal reference is Hotelling (1931). See, also, Ulph and Ulph (1994) and Sinclair (1994).

Information, education and public discussion can play a powerful role in shaping understanding of reasonable behaviour.

Economists tend to put most of weight in public-policy analyses and recommendations on market instruments to which firms and households respond. And there are excellent reasons for this – firms and households know more about their own circumstances and can respond strongly to incentives. But the standard ‘sticks and carrots’ of this line of argument do not constitute the whole story.

Chapter 17 argues that changing attitudes is indeed likely to be a crucial part of a policy package. But it raises ethical difficulties: who has the right or authority to attempt to change preferences or attitudes? We shall adopt the approach of John Stuart Mill and others who have emphasised ‘government by discussion’ as the way in which individuals can come to decisions individually and collectively as to the ethical and other justifications of different approaches to policy.

2.8 International action for mitigation and adaptation

The principles of public policy for mitigation elaborated so far do not take very explicit account of the international nature of the challenge. This is a global problem and mitigation is a global public good. This means that it is, from some perspectives, ‘an international game’ and the theory of games does indeed provide powerful insights. The challenge is to promote and sustain international collective action in a context where ‘free-riding’ is a serious problem. Adaptation, like mitigation, raises strong and difficult international issues of responsibility and equity, and also has some elements of the problem of providing public goods.

Aspects of adaptation to climate change also have some of the characteristics of public goods and require public policy intervention.

Concerns about the provision of public goods affect policy to guide adaptation to the adverse impacts of climate change. This is the subject of Part V of the Review. Compared with efforts to reduce emissions, adaptation provides immediate, local benefits for which there is some degree of private return. Nevertheless, efficient adaptation to climate change is also hindered by market failures, notably inadequate information on future climate change and positive externalities in the provision of adaptation (where the social return remains higher than the return that will be captured by private investors). These market failures may limit the amount of adaptation undertaken – even where it would be cost-effective.

The ethics of adaptation imply strong support from the rich countries to the most vulnerable.

The poorest in society are likely to have the least capacity to adapt, partly because of resource constraints on upfront investment in adaptive capacity. Given that the greatest need for adaptation will be in low-income countries, overcoming financial constraints is also a key objective. This will involve transfers from rich countries to poor countries. The argument is strongly reinforced by the historical responsibility of rich countries for the bulk of accumulated stocks of GHGs. Poor countries are suffering and will suffer from climate change generated in the past by consumption and growth in rich countries.

Action on climate change that is up to the scale of the challenge requires countries to participate voluntarily in a sustained, coordinated, international effort.

Climate change shares some characteristics with other environmental challenges linked to the management of common international resources, including the protection of the ozone layer and the depletion of fisheries. Crucially, there is no global single authority with the legal, moral, practical or other capacity to manage the climate resource.

This is particularly challenging, because, as Chapter 8 makes clear, no one country, region or sector alone can achieve the reductions in GHG emissions required to stabilise atmospheric

concentrations of GHGs at the necessary level. In addition, there are significant gains to co-operating across borders, for example in undertaking emission reductions in the most cost-effective way. The economics and science point to the need for emitters to face a common price of emissions at the margin. And, although adaptation to climate change will often deliver some local reduction in its impact, those countries most vulnerable to climate change are particularly short of the resources to invest in adaptation. Hence international collective action on both mitigation and adaptation is required, and Part VI of the Review discusses the challenges and options.

Economic tools such as game theory, as well as insights from international relations, can aid the understanding of how different countries, with differing incentives, preferences and cost structures, can reach agreement. The problem of free-riding on the actions of others is severe. International collective action on any issue rests on the voluntary co-operation of sovereign states. Economic analysis suggests that multilateral regimes succeed when they are able to define the gain to co-operation, share it equitably and can sustain co-operation in ways that overcome incentives for free-riding.

Our response to climate change as a world is about the choices we make about development, growth, the kind of society we want to live in, and the opportunities it affords this and future generations. The challenge requires focusing on outcomes that promote wealth, consumption, health, reduced mortality and greater social justice.

The empirical analysis of impacts and costs, together with the ethical frameworks we have examined, points to strong action to mitigate GHG emissions. And, given the responsibility of the rich countries for the bulk of the current stock of GHGs, and the poverty and vulnerability of developing countries that would be hardest hit, the analysis suggests that rich countries should bear the major responsibility for providing the resources for adjustment, at least for the next few years. The reasons for strong action by the rich countries are similar to those for aid:

- the moral consequences which flow from a recognition of a common humanity of deep poverty;
- the desire to build a more collaborative, inclusive and better world;
- common interest in the climate and in avoiding dislocation;
- historical responsibility.

2.9 Conclusions

Much of the economics we have begun to describe here and that is put to use in the subsequent parts of this Review is not simple. But the structure of this economics is essentially dictated by the structure of the science. And we have seen that it is not possible to provide a coherent and serious account of the economics of climate change without close attention to the ethics underlying economic policy raised by the challenges of climate change.

The economics of climate change is as broad ranging, deep and complicated as any other area of economics. Indeed, it combines most of the difficulties of other areas of economics. It is unavoidably technical in places. It is the task of this Review to explore the economics of climate change in the depth that is possible given the current state of economic and scientific knowledge. And it should already be clear that much more research is necessary. In many ways, the science has progressed further than the economics.

The scope and depth of the subject require us to put the tools of economics to work across the whole range of the subject. Indeed they point to the importance of tools we wish we had. Nevertheless, the economics can be very powerful in pointing us towards important policy conclusions, as we have already begun to see in this chapter. The urgency of the problems established by the science points to the urgency of translating what we can already show with the economic analysis into concrete policy actions. In doing so, the international dimension must be at centre stage.

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