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Working Group III – Mitigation of Climate Change

Chapter 3

Social, Economic and Ethical Concepts and Methods

Chapter:	3	
Title:	Social, Economic, and Ethical Concepts and Methods	
Authors:	CLAs:	Charles Kolstad, Kevin Urama
	LAs:	John Broome, Annegrete Bruvoll, Micheline Cariño Olvera, Don Fullerton, Christian Gollier, William Michael Hanemann, Rashid Hassan, Frank Jotzo, Mizan R. Khan, Lukas Meyer, Luis Mundaca
	CAs:	Philippe Aghion, Hunt Allcott, Gregor Betz, Severin Borenstein, Andrew Brennan, Simon Caney, Dan Farber, Adam Jaffe, Gunnar Luderer, Axel Ockenfels, David Popp
	REs:	Marlene Attzs, Daniel Bouille, Snorre Kverndokk
	CSAs:	Sheena Katai, Katy Maher, Lindsey Sarquilla

Chapter 3: Social, Economic, and Ethical Concepts and Methods

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Executive Summary

This framing Chapter describes the strengths and limitations of the most widely used concepts and methods in economics ethics, and other social sciences that are relevant to climate change. It also provides a reference resource for the other chapters in the Fifth Assessment Report (AR5), as well as for decision makers.

The significance of the social dimension and the role of ethics and economics is underscored by Article 2 of the United Nations Framework Convention on Climate Change, which indicates that an ultimate objective of the Convention is to avoid dangerous anthropogenic interference with the climate system. Two main issues confronting society (and the IPCC) are: what constitutes 'dangerous interference' with the climate system and how to deal with it. Determining what is dangerous is not a matter for natural science alone; it also involves value judgements – a subject matter of the theory of value, which is treated in several disciplines, including ethics, economics and other social sciences.

Ethics involves questions of justice and value. Justice is concerned with equity and fairness, and, in general, with the rights to which people are entitled. Value is a matter of worth, benefit or good. Value can sometimes be measured quantitatively, for instance, through a social welfare function or an index of human development.

Economic tools and methods can be used in assessing the positive and negative values that result from particular decisions, policies and measures. They can also be essential in determining the mitigation and adaptation actions to be undertaken as public policy, as well as the consequences of different mitigation and adaptation strategies. Economic tools and methods have strengths and limitations, both of which are detailed in this chapter.

Economic tools can be useful in designing climate mitigation policies *(very high confidence)***.** While the limitations of economics and social welfare analysis, including cost-benefit analysis, are widely documented, economics nevertheless provides useful tools for assessing the pros and cons of taking, or not taking, action on climate mitigation, as well as of adaptation measures in achieving competing societal goals. Understanding these pros and cons can help in making policy decisions on climate mitigation and can influence the actions taken by countries, institutions and individuals [3.2].

Mitigation is a public good; climate change is a case of 'the tragedy of the commons' *(high confidence).* Effective climate change mitigation will not be achieved if each agent (individual, institution or country) acts independently in its own selfish interest, suggesting the need for collective action. Some adaptation actions, on the other hand, have characteristics of a private good as benefits of actions may accrue more directly to the individuals, regions or countries which undertake them, at least in the short term. Nevertheless, financing such adaptive activities remains an issue, particularly for poor individuals and countries [3.1].

Analysis contained in the literature of moral and political philosophy can contribute to resolving ethical questions that are raised by climate change (medium confidence). These questions include how much overall climate mitigation is needed to avoid 'dangerous interference', how the effort or cost of mitigating climate change should be shared among countries and between the present and future, how to account for such factors as historical responsibility for emissions, and how to choose among alternative policies for mitigation and adaptation. Ethical issues of wellbeing, justice, fairness, and rights are all involved [3.2, 3.3, 3.4].

Duties to pay for some climate damages can be grounded in compensatory justice and distributive justice *(medium confidence)***.** If compensatory duties to pay for climate damages and adaptation costs are not due from agents who have acted blamelessly, then principles of compensatory justice will apply to only some of the harmful emissions [3.3.5]. This finding is also reflected in the predominant global legal practice of attributing liability for harmful emissions [3.3.6]. Duties to pay for climate damages can, however, also be grounded in distributive justice [3.3.4, 3.3.5].

Distributional weights may be advisable in cost-benefit analysis *(medium confidence).* Ethical theories of value commonly imply that distributional weights should be applied to monetary measures of benefits and harms [3.6.1]. Such weighting contrasts with much of the practice of cost-benefit analysis.

The use of a temporal discount rate has a crucial impact on the evaluation of mitigation policies and measures. The social discount rate is the minimum rate of expected social return that compensates for the increased intergenerational inequalities and the potential increased collective risk that an action generates. Even with disagreement on the level of the discount rate, a consensus favours using declining risk-free discount rates over longer time horizons *(high confidence)* [3.6.2].

An appropriate social risk-free discount rate for consumption is between one and three times the anticipated growth rate in real per capita consumption *(medium confidence).* This judgement is based on an application of the Ramsey rule using typical values in the literature of normative parameters in the rule. Ultimately, however, these are normative choices [3.6.2].

Co-benefits may complement the direct benefits of mitigation *(medium confidence).* While some direct benefits of mitigation are reductions in adverse climate change impacts, co-benefits can include a broad range of environmental, economic and social effects, such as reductions in local air pollution, less acid rain, and increased energy security. However, whether co-benefits are net positive or negative in terms of wellbeing (welfare) can be difficult to determine because of interaction between climate policies and pre-existing non-climate policies. The same results apply to adverse side effects [3.6.3].

Tax distortions change the cost of all abatement policies *(high confidence).* A carbon tax or a tradable emissions permit system can exacerbate tax distortions, or, in some cases, alleviate them; carbon tax or permit revenue can be used to moderate adverse effects by cutting other taxes. However, regulations that forgo revenue (e.g., by giving permits away) implicitly have higher social costs because of the tax interaction effect. [3.6.3]

Many different analytic methods are available for evaluating policies. Methods may be quantitative (for example, cost-benefit analysis, integrated assessment modelling and multi-criteria analysis) or qualitative (for example, sociological and participatory approaches). However, no single-best method can provide a comprehensive analysis of policies. A mix of methods is often needed to understand the broad effects, attributes, trade-offs and complexities of policy choices; moreover, policies often address multiple objectives [3.7].

Four main criteria are frequently used in evaluating and choosing a mitigation policy *(medium confidence).* They are: cost-effectiveness and economic efficiency (excluding environmental benefits, but including transaction costs); environmental effectiveness (the extent to which the environmental targets are achieved); distributional effects (impact on different subgroups within society); and institutional feasibility, including political feasibility [3.7.1].

A broad range of policy instruments for climate change mitigation is available to policymakers. These include: economic incentives, direct regulatory approaches, information programmes, government provision and voluntary actions. Interactions between policy instruments can enhance or reduce the effectiveness and cost of mitigation action. Economic incentives will generally be more cost-effective than direct regulatory interventions. However, the performance and suitability of policies depends on numerous conditions, including institutional capacity, the influence of rent-seeking, and predictability or uncertainty about future policy settings. The enabling environment may differ between countries, including between low-income and high-income countries. These differences can have implications for the suitability and performance of policy instruments [3.8].

Impacts of extreme events may be more important economically than impacts of average climate change *(high confidence).* Risks associated with the entire probability distribution of outcomes in terms of climate response [WG1] and climate impacts [WG2] are relevant to the assessment of mitigation. Impacts from more extreme climate change may be more important economically (in terms of the expectation of impacts) than impacts of average climate change, particularly if the damage from extreme climate change increases more rapidly than the probability of such change declines. This is important in economic analysis, where the *expected* benefit of mitigation may be traded off against mitigation costs [3.9.2].

Impacts from climate change are both market and non-market. Market effects (where market prices and quantities are observed) include impacts of storm damage on infrastructure, tourism and increased energy demand. Non-market effects include many ecological impacts, as well as changed cultural values, none of which are generally captured through market prices. The economic measure of the value of either kind of impact is 'willingness-to-pay' to avoid damage, which can be estimated using methods of revealed preference and stated preference [3.9].

Substitutability reduces the size of damages from climate change *(high confidence)***.** The monetary damage from a change in the climate will be lower if individuals can easily substitute for what is damaged, compared to cases where such substitution is more difficult [3.9].

Damage functions in existing Integrated Assessment Models (IAMs) are of low reliability *(high confidence)***.** The economic assessments of damages from climate change as embodied in the damage functions used by some existing IAMs (though not in the analysis embodied in WGIII) are highly stylized with a weak empirical foundation. The empirical literature on monetized impacts is growing but remains limited and often geographically narrow [3.9].

Negative private costs of mitigation arise in some cases, although they are sometimes overstated in the literature *(medium confidence).* Sometimes mitigation can lower the private costs of production and thus raise profits; for individuals, mitigation can raise wellbeing. Ex-post evidence suggests that such 'negative cost opportunities' do indeed exist but are sometimes overstated in engineering analyses [3.9].

Exchange rates between GHGs with different atmospheric lifetimes are very sensitive to the choice of emission metric. The choice of an emission metric depends on the potential application and involves explicit or implicit value judgements; no consensus surrounds the question which metric is both conceptually best and practical to implement (high confidence). In terms of aggregate mitigation costs alone, the Global Warming Potential, with a 100 year time horizon, may perform similarly to selected other metrics (such as the time-dependent Global Temperature Change Potential or the Global Cost Potential) of reaching a prescribed climate target; however, various metrics may differ significantly in terms of the implied distribution of costs across sectors, regions and over time *(limited evidence, medium agreement*) [3.9].

The behaviour of energy users and producers exhibits a variety of anomalies *(high confidence).* Understanding climate change as a physical phenomenon with links to societal causes and impacts is a very complex process. To be fully effective, the conceptual frameworks and methodological tools used in mitigation assessments need to take into account cognitive limitations and other-regarding preferences that frame the processes of economic decision making by people and firms [3.10].

Perceived fairness can facilitate cooperation among individuals *(high confidence).* Experimental evidence suggests that reciprocal behaviour and perceptions of fair outcomes and procedures facilitate voluntary cooperation among individual people in providing public goods; this finding may have implications for the design of international agreements to coordinate climate mitigation [3.10].

Social institutions and culture can facilitate mitigation and adaptation *(medium confidence).* Social institutions and culture can shape individual actions on mitigation and adaptation and be complementary to more conventional methods for inducing mitigation and adaptation. They can promote trust and reciprocity and contribute to the evolution of common rules. They also provide structures for acting collectively to deal with common challenges [3.10].

Technological change that reduces mitigation costs can be encouraged by institutions and economic incentives *(high confidence).* As pollution is not fully priced by the market, private individuals and firms lack incentives to invest in the development and use of emissions-reducing technologies in the absence of appropriate policy interventions. Moreover, imperfect appropriability of the benefits of innovation further reduces incentives to develop new technologies [3.11].

3.1 Introduction

This framing Chapter has two primary purposes: to provide a framework for viewing and understanding the human (social) perspective on climate change, focusing on ethics and economics; and to define and discuss key concepts used in other chapters. It complements the two other framing chapters: Chapter 2 on risk and uncertainty and Chapter 4 on sustainability. The audience for this Chapter (indeed for this entire volume) is decision makers at many different levels.

The significance of the social dimension and the role of ethics and economics is underscored by Article 2 of the Framework Convention on Climate Change, which indicates that the ultimate objective of the Convention is to avoid dangerous anthropogenic interference with the climate system. Two main issues confronting society are: what constitutes 'dangerous interference' with the climate system and how to deal with it. Providing information to answer these inter-related questions is a primary purpose of the IPCC. Although natural science helps us understand how emissions can change the climate, and, in turn, generate physical impacts on ecosystems, people and the physical environment, determining what is dangerous involves judging the level of adverse consequences, the steps necessary to mitigate these consequences and risk that humanity is willing to tolerate. These are questions requiring value judgement. Although economics is essential to evaluating the consequences and trade-offs associating with climate change, how society interprets and values them is an ethical question.

Box 3.1 Dangerous Interference with the Climate System

Article 2 of the United Nations Framework Convention on Climate Change states that "the ultimate objective of the Convention . . . is to achieve . . . stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." Judging whether our interference in the climate system is dangerous, i.e., risks causing a very bad outcome, involves two tasks: estimating the physical consequences of our interference and their likelihood; and assessing their significance for people. The first falls to science, but, as the Synthesis Report of the IPCC Fourth Assessment Report (AR4) states, "Determining what constitutes 'dangerous anthropogenic interference with the climate system' in relation to Article 2 of the UNFCCC involves value judgements" (IPCC, 2007, p. 42). Value judgements are governed by the theory of value. In particular, valuing risk is covered by decision theory and is dealt with in Chapter 2. Central questions of value that come within the scope of ethics, as well as economic methods for measuring certain values are examined in this chapter.

Our discussion of ethics centres on two main considerations: justice and value. Justice requires that people and nations should receive what they are due, or have a right to. For some, an outcome is just if the process that generated it is just. Others view justice in terms of the actual outcomes enjoyed by different people and groups and the values they place on those outcomes. Outcome-based justice can range from maximizing economic measures of aggregate welfare to rights-based views of justice, for example, believing that all countries have a right to clean air. Different views have been expressed about what is valuable. All values may be anthropocentric or there may be non-human values. Economic analysis can help to guide policy action, provided that appropriate, adequate and transparent ethical assumptions are built into the economic methods.

The significance of economics in tackling climate change is widely recognized. For instance, central to the politics of taking action on climate change are disagreements over how much mitigation the world should undertake, and the economic costs of action (the costs of mitigation) and inaction (the costs of adaptation and residual damage from a changed climate). Uncertainty remains about (1) the costs of reducing emissions of greenhouse gases (GHGs), (2) the damage caused by a change in the climate, and (3) the cost, practicality, and effectiveness of adaptation measures (and, potentially, geoengineering). Prioritizing action on climate change over other significant social goals with more near-term payoffs is particularly difficult in developing countries. Because social concerns and objectives, such as the preservation of traditional values, cannot always be easily quantified or monetized, economic costs and benefits are not the only input into decision-making about climate change. But even where costs and benefits can be quantified and monetized, using methods of economic analysis to steer social action implicitly involves significant ethical assumptions. This Chapter explains the ethical assumptions that must be made for economic methods, including cost-benefit analysis (CBA), to be valid, as well as the ethical assumptions that are implicitly being made where economic analysis is used to inform a policy choice.

The perspective of economics can improve our understanding of the difficulties of acting on mitigation. For an individual or firm, mitigation involves real costs, while the benefits to themselves of their own mitigation efforts are small and intangible. This reduces the incentives for individuals or countries to unilaterally reduce emissions; free-riding on the actions of others is a dominant strategy. Mitigating greenhouse gas (GHG) emissions is a public good, which inhibits mitigation. This also partly explains the failure of nations to agree on how to solve the problem.

In contrast, adaptation tends not to suffer from free-riding. Gains to climate change from adaptation, such as planting more heat tolerant crops, are mainly realized by the parties who incur the costs. Associated externalities tend to be more localized and contemporaneous than for GHG mitigation. From a public goods perspective, global coordination may be less important for many forms of adaptation than for mitigation. For autonomous adaptation in particular, the gains from adaptation accrue to the party incurring the cost. However, public adaptation requires local or regional coordination. Financial and other constraints may restrict the pursuit of attractive adaptation opportunities, particularly in developing countries and for poorer individuals.

This Chapter addresses two questions: what *should be done* about action to mitigate climate change (a normative issue) and how the world works in the multifaceted context of climate change (a descriptive or positive issue). Typically, ethics deals with normative questions and economics with descriptive or normative questions. Descriptive questions are primarily value-neutral, for example, how firms have reacted to cap-and-trade programmes to limit emissions, or how societies have dealt with responsibility for actions that were not known to be harmful when they were taken. Normative questions use economics and ethics to decide what *should* be done, for example, determining the appropriate level of burden sharing among countries for current and future mitigation. In making decisions about issues with normative dimensions, it is important to understand the implicit assumptions involved. Most normative analyses of solutions to the climate problem implicitly involve contestable ethical assumptions.

This Chapter does not attempt to answer ethical questions, but rather provides policymakers with the tools (concepts, principles, arguments and methods) to make decisions. Summarizing the role of economics and ethics in climate change in a single chapter necessitates several caveats. While recognizing the importance of certain non-economic social dimensions of the climate change problem and solutions to it, space limitations and our mandate necessitated focusing primarily on ethics and economics. Furthermore, many of the issues raised have already been addressed in previous IPCC assessments, particularly AR2 (published in 1995). In the past, ethics has received less attention than economics, although aspects of both subjects are covered in AR2. The literature reviewed here includes pre-AR4 literature in order to provide a more comprehensive understanding of the concepts and methods. We highlight ‘new’ developments in the field since the last IPCC assessment in 2007.

3.2 Ethical and socio-economic concepts and principles

When a country emits GHGs, its emissions cause harm around the globe. The country itself suffers only a part of the harm it causes. It is therefore rarely in the interests of a single country to reduce its own emissions, even though a reduction in global emissions could benefit every country. That is to say, the problem of climate change is a “tragedy of the commons” (Hardin, 1968). Effective mitigation of climate change will not be achieved if each person or country acts independently in its own interest.

Consequently, efforts are continuing to reach effective international agreement on mitigation. They raise an ethical question that is widely recognized and much debated, namely, ‘burden-sharing’ or ‘effort-sharing’. How should the burden of mitigating climate change be divided among countries? It raises difficult issues of justice, fairness and rights, all of which lie within the sphere of ethics.

It is only one of the ethical questions that climate change raises.[1] Another is the question of how much overall mitigation should take place. The United Nations Framework Convention on Climate Change (UNFCCC) sets the aim of “avoiding dangerous anthropogenic interference with the climate system”, and judging what is dangerous is partly a task for ethics (see Box 3.1). Besides justice, fairness and rights, a central concern of ethics is *value*. Judgements of value underlie the question of what interference with the climate system would be dangerous.

Indeed, ethical judgements of value underlie almost every decision that is connected with climate change, including decisions made by individuals, public and private organizations, governments and groupings of governments. Some of these decisions are deliberately aimed at mitigating climate change or adapting to it. Many others influence the progress of climate change or its impacts, so they need to take climate change into account.

Ethics may be broadly divided into two branches: justice and value. Justice is concerned with ensuring that people get what is *due* to them. If justice requires that a person should not be treated in a particular way – uprooted from her home by climate change, for example – then the person has a *right* not to be treated that way. Justice and rights are correlative concepts. On the other hand, criteria of value are concerned with improving the world: making it a better place. Synonyms for ‘value’ in this context are ‘good’, ‘goodness’ and ‘benefit’. Antonyms are ‘bad’, ‘harm’ and ‘cost’.

To see the difference between justice and value, think of a transfer of wealth made by a rich country to a poor one. This may be an act of restitution. For example, it may be intended to compensate the poor country for harm that has been done to it by the rich country’s emissions of GHG. In this case, the transfer is made on grounds of justice. The payment is taken to be due to the poor country, and to satisfy a right that the poor country has to compensation. Alternatively, the rich country may make the transfer to support the poor country’s mitigation effort, because this is beneficial to people in the poor country, the rich country and elsewhere. The rich country may not believe the poor country has a right to the support, but makes the payment simply because it does good. This transfer is made on grounds of value. What would be good to do is not necessarily required as a matter of justice. Justice is concerned with what people are entitled to as a matter of their rights.

The division between justice and value is contested within moral philosophy, and so is the nature of the interaction between the two. Some authors treat justice as inviolable (Nozick, 1974): justice sets limits on what we may do and we may promote value only within those limits. An opposite view – called ‘teleological’ by Rawls (1971) – is that the right decision to make is always determined by the value of the alternatives, so justice has no role. But despite the complexity of their relationship and the controversies it raises, the division between justice and value provides a useful basis for organizing the discussion of ethical concepts and principles. We have adopted it in this Chapter: Sections 3.3 and 3.4 cover justice and value, respectively. One topic appears in both Sections because it bridges the divide: this topic is distributive justice viewed one way and the value of equality viewed the other. Subsection 3.3.7 on geoengineering is also in an intermediate position because it raises ethical issues of both sorts. Section 3.6 explains how some ethical values can be

[1] A survey of the ethics of climate change is Gardiner (2004), pp. 555-600.

measured by economic methods of valuation. Section 3.5 describes the scope and limitations of these methods. Later sections develop the concepts and methods of economics in more detail. Practical ways to take account of different values in policy-making are discussed in Subsection 3.7.1 .

3.3 Justice, equity and responsibility

Justice, fairness, equity and responsibility are important in international climate negotiations, as well as in climate-related political decision-making within countries and for individuals.

In this Section we examine distributive justice, which, for the purpose of this review, is about outcomes, and procedural justice or the way in which outcomes are brought about. We also discuss compensation for damage and historic responsibility for harm. In the context of climate change, considerations of justice, equity and responsibility concern the relations between individuals, as well as groups of individuals (e.g., countries), both at a single point in time and across time. Accordingly we distinguish intra-generational from intergenerational justice. The literature has no agreement on a correct answer to the question, what is just? We indicate where opinions differ.

3.3.1 Causal and moral responsibility

From the perspective of countries rather than individuals or groups of individuals, the developed countries bear much of the causal responsibility for climate change because of their historical emissions (den Elzen et al., 2005; Lamarque et al., 2010; Höhne et al., 2011). Furthermore, many developed countries are expected to suffer relatively modest physical damage and some are even expected to realize benefits from future climate change (see Tol, 2002a; b). On the other hand, many developing countries bear less causal responsibility, but they could suffer significant physical damage from climate change (IPCC, 2007 WG II AR4 SPM). This asymmetry gives rise to the following questions of justice and moral responsibility: do considerations of justice provide guidance in determining the appropriate level of present and future global emissions; the distribution of emissions among those presently living; and the role of historical emissions in distributing global obligations? The question also arises of who might be considered morally responsible for achieving justice, and, thus, a bearer of duties towards others. The question of moral responsibility is also key to determining whether anyone owes compensation for the damage caused by emissions.

3.3.2 Intergenerational justice and rights of future people

Intergenerational justice encompasses some of the moral duties owed by present to future people and the rights that future people hold against present people.[2] A legitimate acknowledgment that future or past generations have rights relative to present generations is indicative of a broad understanding of justice.[3] While justice considerations so understood are relevant, they cannot cover all our concerns regarding future and past people, including the continued existence of humankind and with a high level of wellbeing.[4]

What duties do present generations owe future generations given that current emissions will affect their quality of life? Some justice theorists have offered the following argument to justify a cap on

[2] In the philosophical literature, “justice between generations” typically refers to the relations between people whose lifetimes do not overlap (Barry, 1977). In contrast, “justice between age groups” refers to the relations of people whose lifetimes do overlap (Laslett and Fishkin, 1992). See also Gardiner (2011), pp 145-48.

[3] See Rawls (1971, 1999), Barry (1977), Sikora and Barry (1978), Partridge (1981), Parfit (1986), Birnbacher (1988) and Heyd (1992).

[4] See Baier (1981), De-Shalit (1995), Meyer (2005), and for African philosophical perspectives see, Behrens (2012). See section 3.4 on the wellbeing of future people.

emissions (Shue, 1993, 1999; Caney, 2006a; Meyer and Roser, 2009; Wolf, 2009). If future people's basic rights include the right to survival, health and subsistence, these basic rights are likely to be violated when temperatures rise above a certain level. However, currently living people can slow the rise in temperature by limiting their emissions at a reasonable cost to themselves. Therefore, living people should reduce their emissions in order to fulfil their minimal duties of justice to future generations. Normative theorists dispute the standard of living that corresponds to people's basic rights (Page, 2007; Huseby, 2010). It is also in dispute what level of harm imposed on future people is morally objectionable. Some argue that currently living people wrongfully harm future people if they cause them to have a lower level of wellbeing than their own (e.g., Barry, 1999); others that currently living people owe future people a decent level of wellbeing, which might be lower than their own (Wolf, 2009). This argument raises objections on grounds of justice since it presupposes that present people can violate the rights of future people, and that the protection of future people's rights is practically relevant for how present people ought to act.

Some theorists claim that future people cannot hold rights against present people owing to special features of intergenerational relations: some claim that future people cannot have rights because they cannot exercise them today (Steiner, 1983; Wellman, 1995, ch. 4). Others point out that interaction between non-contemporaries is impossible (Barry, 1977, pp. 243–244, 1989, p. 189). However, some justice theorists argue that neither the ability to, nor the possibility of, mutual interaction are necessary in attributing rights to people (Barry, 1989; Buchanan, 2004). They hold that rights are attributed to beings whose interests are important enough to justify imposing duties on others.

The main source of scepticism about the rights of future people and the duties we owe them is the so-called 'non-identity problem'. Actions we take to reduce our emissions will change people's way of life and so affect new people born. They alter the identities of future people. Consequently, our emissions do not make future people worse off than they would otherwise have been, since those future people would not exist if we took action to prevent our emissions. This makes it hard to claim that our emissions harm future people, or that we owe it to them as a matter of their rights to reduce our emissions.[5]

It is often argued that the non-identity problem can be overcome (McMahan, 1998; Shiffrin, 1999; Kumar, 2003; Meyer, 2003; Harman, 2004; Reiman, 2007; Shue, 2010). In any case, duties of justice do not include all the moral concerns we should have for future people. Other concerns are matters of value rather than justice, and they too can be understood in such a way that they are not affected by the non-identity problem. They are considered in Section 3.4 .

If present people have a duty to protect future people's basic rights, this duty is complicated by uncertainty. Present people's actions or omissions do not necessarily violate future people's rights; they create a risk of their rights being violated (Bell, 2011). To determine what currently living people owe future people one has to weigh such uncertain consequences against other consequences of their actions, including the certain or likely violation of the rights of currently living people (Oberdiek, 2012; Temkin, 2012). This is important in assessing many long-term policies, including on geoengineering (see Subsection 3.3.7), that risk violating the rights of many generations of people (Crutzen, 2006; Schneider, 2008; Victor et al., 2009; Baer, 2010; Ott, 2012).

3.3.3 Intergenerational justice: distributive justice

Suppose that a global emissions ceiling that is intergenerationally just has been determined (recognizing that a ceiling is not the only way to deal with climate change), the question then arises of how the ceiling ought to be divided among states (and, ultimately, their individual members)

[5] For an overview of the issue see Meyer (2010). See also Schwartz (1978), Parfit (1986), and Heyd (1992). For a different perspective see Perrett (2003).

(Jamieson, 2001; Singer, 2002; Meyer and Roser, 2006; Caney, 2006a). Distributing emission permits is a way of arriving at a globally just division. Among the widely discussed views on distributive justice are strict egalitarianism (Temkin, 1993), indirect egalitarian views including prioritarianism (Parfit, 1997), and sufficientarianism (Frankfurt, 1999). Strict egalitarianism holds that equality has value in itself. Prioritarianism gives greater weight to a person's wellbeing the less well off she is, as described in Section 3.4 . Sufficientarianism recommends that everyone should be able to enjoy a particular level of wellbeing.

Two options can help apply prioritarianism to the distribution of freely allocated and globally tradeable emission permits. The first is to ignore the distribution of other goods. Then strict egalitarianism or prioritarianism will require emission permits to be distributed equally, since they will have one price and are thus equivalent to income. The second is to take into account the unequal distribution of other assets. Since people in the developing world are less well off than in the developed world, strict egalitarianism or prioritarianism would require most or all permits to go to the developing world. However, it is questionable whether it is appropriate to bring the overall distribution of goods closer to the prioritarian ideal through the distribution of just one good (Wolff and de-Shalit, 2007; Caney, 2009, 2012).

3.3.4 Historical responsibility and distributive justice

Historical responsibility for climate change depends on countries' contributions to the stock of GHGs. The UNFCCC refers to "common but differentiated responsibilities" among countries of the world. This is sometimes taken to imply that current and historical causal responsibility for climate change should play a role in determining the obligations of different countries in reducing emissions and paying for adaptation measures globally (Rajamani, 2000; Rive et al., 2006; Friman, 2007).

A number of objections have been raised against the view that historical emissions should play a role (see, e.g., Gosseries, 2004; Caney, 2005; Meyer and Roser, 2006; Posner and Weisbach, 2010). First, as currently living people had no influence over the actions of their ancestors, they cannot be held responsible for them. Second, previously living people may be excused from responsibility on the grounds that they could not be expected to know that their emissions would have harmful consequences. Thirdly, present individuals with their particular identities are not worse off as a result of the emission-generating activities of earlier generations because, owing to the non-identity problem, they would not exist as the individuals they are had earlier generations not acted as they did.

From the perspective of distributive justice, however, these objections need not prevent past emissions and their consequences being taken into account (Meyer and Roser, 2010; Meyer, 2013). If we are only concerned with the distribution of benefits from emission-generating activities during an individual's lifespan, we should include the benefits present people have received from their own emission-generating activities. Furthermore, present people have benefited since birth or conception from past people's emission-producing actions. They are therefore better off as a result of past emissions, and any principle of distributive justice should take that into account. Some suggest that taking account of the consequences of some past emissions in this way should not be subject to the objections mentioned in the previous paragraph (see Shue, 2010). Other concepts associated with historical responsibility are discussed in Chapter 4.

3.3.5 Intra-generational justice: compensatory justice and historical responsibility

Do those who suffer disproportionately from the consequences of climate change have just claims to compensation against the main perpetrators or beneficiaries of climate change (see, e.g., Neumayer, 2000; Gosseries, 2004; Caney, 2006b)?

One way of distinguishing compensatory from distributive claims is to rely on the idea of a just baseline distribution that is determined by a criterion of distributive justice. Under this approach, compensation for climate damage and adaptation costs is owed only by people who have acted wrongfully according to normative theory (Feinberg, 1984; Coleman, 1992; McKinnon, 2011). Other deviations from the baseline may warrant redistributive measures to redress undeserved benefits or harms, but not as compensation. Some deviations, such as those that result from free choice, may not call for any redistribution at all.

The duty to make compensatory payments (Gosseries, 2004; Caney, 2006b) may fall on those who emit or benefit from wrongful emissions or who belong to a community that produced such emissions. Accordingly, three principles of compensatory justice have been suggested: the polluter pays principle (PPP), the beneficiary pays principle (BPP) and the community pays principle (CPP) (Meyer and Roser, 2010; Meyer, 2013), of which the PPP is more widely accepted than the others. The PPP requires the emitter to pay compensation if the agent emitted more than her fair share (determined as outlined in Subsection 3.3.2) and she either knew, or could reasonably be expected to know, that her emissions were harmful. The victim should be able to show that the emissions either made her worse off than before or pushed her below a specified threshold of harm, or both.

The right to compensatory payments for wrongful emissions under PPP has at least three basic limitations. Two have already been mentioned in Subsection 3.3.4 . Emissions that took place while it was permissible to be ignorant of climate change (when people neither did know nor could be reasonably be expected to know about the harmful consequences of emissions) may be excused (Gosseries, 2004, pp. 39–41). See also Subsection 3.3.6 . The non-identity problem (see Subsection 3.3.2) implies that earlier emissions do not harm many of the people who come into existence later. Potential duty bearers may be dead and cannot therefore have a duty to supply compensatory measures. It may therefore be difficult to use PPP in ascribing compensatory duties and identifying wronged persons. The first and third limitations restrict the assignment of duties of compensation to currently living people for their most recent emissions, even though many more people are causally responsible for the harmful effects of climate change. For future emissions, the third limitation could be overcome through a climate change compensation fund into which agents pay levies for imposing the risk of harm on future people (McKinnon, 2011).

According to BPP, a person who is wrongfully better off relative to a just baseline is required to compensate those who are worse off. Past emissions benefit some and impose costs on others. If currently living people accept the benefits of wrongful past emissions, it has been argued that they take on some of the past wrongdoer's duty of compensation (Gosseries, 2004). Also we have a duty to condemn injustice, which may entail a duty not to benefit from an injustice that causes harm to others (Butt, 2007). However, BPP is open to at least two objections. First, duties of compensation arise only from past emissions that have benefited present people; no compensation is owed for other past emissions. Second, if voluntary acceptance of benefits is a condition of their giving rise to compensatory duties, the bearers of the duties must be able to forgo the benefits in question at a reasonable cost.

Under CPP moral duties can be attributed to people as members of groups whose identity persists over generations (De-Shalit, 1995; Thompson, 2009). The principle claims that members of a community, including a country, can have collective responsibility for the wrongful actions of other past and present members of the community, even though they are not morally or causally responsible for those actions (Thompson, 2001; Miller, 2004; Meyer, 2005). It is a matter of debate under what conditions present people can be said to have inherited compensatory duties. Although CPP purports to overcome the problem that a polluter might be dead, it can justify compensatory measures only for emissions that are made wrongfully. It does not cover emissions caused by agents who were permissibly ignorant of their harmfulness. (The agent in this case may be the community or state).

The practical relevance of principles of compensatory justice is limited. Insofar as the harms and benefits of climate change are undeserved, distributive justice will require them to be evened out, independently of compensatory justice. Duties of distributive justice do not presuppose any wrongdoing (see Subsection 3.3.4). For example, it has been suggested on grounds of distributive justice that the duty to pay for adaptation should be allocated on the basis of people's ability to pay, which partly reflects the benefit they have received from past emissions (Jamieson, 1997; Shue, 1999; Caney, 2010; Gardiner, 2011). However, present people and governments can be said to know about both the seriously harmful consequences of their emission-generating activities for future people and effective measures to prevent those consequences. If so and if they can implement these measures at a reasonable cost to themselves to protect future people's basic rights (see, e.g., Birnbacher, 2009; Gardiner, 2011), they might be viewed as owing intergenerational duties of justice to future people (see Section 3.3.2).

3.3.6 Legal concepts of historical responsibility

Legal systems have struggled to define the boundaries of responsibility for harmful actions and are only now beginning to do so for climate change. It remains unclear whether national courts will accept lawsuits against GHG emitters, and legal scholars vigorously debate whether liability exists under current law (Mank, 2007; Burns and Osofsky, 2009; Faure and Peeters, 2011; Haritz, 2011; Kosolapova, 2011; Kysar, 2011; Gerrard and Wannier, 2012). This Section is concerned with moral responsibility, which is not the same as legal responsibility. But moral thinking can draw useful lessons from legal ideas.

Harmful conduct is generally a basis for liability only if it breaches some legal norm (Tunc, 1983), such as negligence, or if it interferes unreasonably with the rights of either the public or property owners (Mank, 2007; Grossman, 2009; Kysar, 2011; Brunée et al., 2012; Goldberg and Lord, 2012; Koch et al., 2012). Liability for nuisance does not exist if the agent did not know, or have reason to know, the effects of her conduct (Antolini and Rechtschaffen, 2008). The law in connection with liability for environmental damage still has to be settled. The European Union, but not the United States, recognizes exemption from liability for lack of scientific knowledge (United States Congress, 1980; European Union, 2004). Under European law, and in some US states, defendants are not responsible if a product defect had not yet been discovered (European Commission, 1985; Dana, 2009). Some legal scholars suggest that assigning blame for GHG emissions dates back to 1990 when the harmfulness of such emissions was established internationally, but others argue in favour of an earlier date (Faure and Nollkaemper, 2007; Hunter and Salzman, 2007; Haritz, 2011). Legal systems also require a causal link between a defendant's conduct and some identified harm to the plaintiff, in this case from climate change (Tunc, 1983; Faure and Nollkaemper, 2007; Kosolapova, 2011; Kysar, 2011; Brunée et al., 2012; Ewing and Kysar, 2012; Goldberg and Lord, 2012). A causal link might be easier to establish between emissions and adaptation costs (Farber, 2007). Legal systems generally also require causal foreseeability or directness (Mank, 2007; Kosolapova, 2011; van Dijk, 2011; Ewing and Kysar, 2012), although some statutes relax this requirement in specific cases (such as the US CERCLA/Superfund). Emitters might argue that their contribution to GHG levels was too small and the harmful effects too indirect and diffuse to satisfy the legal requirements (Sinnot-Armstrong, 2010; Faure and Peeters, 2011; Hiller, 2011; Kysar, 2011; van Dijk, 2011; Gerrard and Wannier, 2012).

Climate change claims could also be classified as unjust enrichment (Kull, 1995; Birks, 2005), but legal systems do not remedy all forms of enrichment that might be regarded as ethically unjust (Zimmermann, 1995; American Law Institute, 2011; Laycock, 2012). Under some legal systems, liability depends on whether benefits were conferred without legal obligation or through a transaction with no clear change of ownership (Zimmermann, 1995; American Law Institute, 2011; Laycock, 2012). It is not clear that these principles apply to climate change.

As indicated, legal systems do not recognize liability just because a positive or negative externality exists. Their response depends on the behaviour that caused the externality and the nature of the causal link between the agent's behaviour and the resulting gain or loss to another.

3.3.7 Geoengineering, ethics, and justice

Geoengineering (also known as climate engineering (CE)), is large-scale technical intervention in the climate system that aims to cancel some of the effects of GHG emissions (for more details see WGI 6.5 and WGIII 6.9). It represents a third kind of response to climate change, besides mitigation and adaptation. Various options for geoengineering have been proposed, including different types of solar radiation management (SRM) and carbon dioxide removal (CDR). This Section reviews the major moral arguments for and against geoengineering technologies (for surveys see Robock, 2008; Corner and Pidgeon, 2010; Gardiner, 2010; Ott, 2010; Betz and Cacean, 2012; Preston, 2013). These moral arguments do not apply equally to all proposed geoengineering methods and have to be assessed on a case-specific basis.[6]

Three lines of argument support the view that geoengineering technologies might be desirable to deploy at some point in the future. First, that humanity could end up in a situation where deploying geoengineering, particularly SRM, appears as a lesser evil than unmitigated climate change (Crutzen, 2006; Gardiner, 2010; Keith et al., 2010; Svoboda, 2012a; Betz, 2012). Second, that geoengineering could be a more cost-effective response to climate change than mitigation or adaptation (Keith, 2000; Barrett, 2008). Such efficiency arguments have been criticized in the ethical literature for neglecting issues such as side-effects, uncertainties or fairness (Gardiner, 2010, 2011; Buck, 2012). Thirdly, that some aggressive climate stabilization targets cannot be achieved through mitigation measures alone and thus must be complemented by either CDR or SRM (Greene et al., 2010; Sandler, 2012).

Geoengineering technologies face several distinct sets of objections. Some authors have stressed the substantial uncertainties of large-scale deployment (for overviews of geoengineering risks see also Schneider (2008) and Sardemann and Grunwald (2010)), while others have argued that some intended and unintended effects of both CDR and SRM could be irreversible (Jamieson, 1996) and that somecurrent uncertainties are unresolvable (Bunzl, 2009). Furthermore, it has been pointed out that geoengineering could make the situation worse rather than better (Hegerl and Solomon, 2009; Fleming, 2010; Hamilton, 2013) and that several technologies lack a viable exit option: SRM in particular would have to be maintained as long as GHG concentrations remain elevated (The Royal Society, 2009).

Arguments against geoengineering on the basis of fairness and justice deal with the intra-generational and intergenerational distributional effects. SRM schemes could aggravate some inequalities if, as expected, they modify regional precipitation and temperature patterns with unequal social impacts (Bunzl, 2008; The Royal Society, 2009; Svoboda et al., 2011; Preston, 2012). Furthermore, some CDR methods would require large-scale land transformations, potentially competing with agricultural land-use, with uncertain distributive consequences. Other arguments against geoengineering deal with issues including the geopolitics of SRM, such as international conflicts that may arise from the ability to control the “global thermostat” (Schelling, 1996; Hulme, 2009), ethics (Hale and Grundy, 2009; Preston, 2011; Hale and Dilling, 2011; Svoboda, 2012b; Hale, 2012b), and a critical assessment of technology and modern civilization in general (Fleming, 2010; Scott, 2012).

One of the most prominent arguments against geoengineering suggests that geoengineering research activities might hamper mitigation efforts (e.g., Jamieson, 1996; Keith, 2000; Gardiner, 2010), which presumes that geoengineering should not be considered an acceptable substitute for

[6] While the literature typically associates some arguments with particular types of methods (e.g., the termination problem with SRM), it is not clear that there are two groups of moral arguments: those applicable to all SRM methods on the one side and those applicable to all CDR methods on the other side. In other words, the moral assessment hinges on aspects of geoengineering that are not connected to the distinction between SRM and CDR.

mitigation. The central idea is that research increases the prospect of geoengineering being regarded as a serious alternative to emission reduction (for a discussion of different versions of this argument see Hale, 2012a; Hourdequin, 2012). Other authors have argued, based on historical evidence and analogies to other technologies, that geoengineering research might make deployment inevitable (Jamieson, 1996; Bunzl, 2009), or that large-scale field tests could amount to full-fledged deployment (Robock et al., 2010). It has also been argued that geoengineering would constitute an unjust imposition of risks on future generations, because the underlying problem would not be solved but only counteracted with risky technologies (Gardiner, 2010; Ott, 2012; Smith, 2012). The latter argument is particularly relevant to SRM technologies that would not affect greenhouse gas concentrations, but it would also apply to some CDR methods as there may be issues of long-term safety and capacity of storage.

Arguments in favour of research on geoengineering point out that research does not necessarily prepare for future deployment, but can, on the contrary, uncover major flaws in proposed schemes, avoid premature CE deployment and eventually foster mitigation efforts (e.g., Keith et al., 2010). Another justification for R&D is that it is required to help decision-makers take informed decisions (Leisner and Müller-Klieser, 2010).

3.4 Values and wellbeing

One branch of ethics is the theory of value. Many different sorts of value can arise, and climate change impinges on many of them. It affects nature and many aspects of human life. This Section surveys some of the values at stake in climate change, and examines how far these values can be measured, combined or weighed against each other. Each value is subject to debate and disagreement. For example, it is debatable whether nature has value in its own right, apart from the benefit it brings to human beings. Decision making about climate change is therefore likely to be contentious.

Since values constitute only one part of ethics, if an action will increase value overall it by no means follows that it should be done. Many actions benefit some people at the cost of harming others. This raises a question of justice even if the benefits in total exceed the costs. Whereas a cost to a person can be compensated for by a benefit to that same person, a cost to a person cannot be compensated for by a benefit to someone else. To suppose it can is not to “take seriously the distinction between persons”, as John Rawls puts it (1971, p. 27). Harming a person may infringe her rights, or it may be unfair to her. For example, when a nation’s economic activities emit GHG, they may benefit the nation itself, but may harm people in other nations. Even if the benefits are greater in value than the harms, these activities may infringe other nations’ rights. Other nations may therefore be entitled to object to them on grounds of justice.

Any decision about climate change is likely to promote some values and damage others. These may be values of very different sorts. In decision making, different values must therefore be put together or balanced against each other. Some pairs of values differ so radically from each other that they cannot be determinately weighed together. For example, it may be impossible to weigh the value of preserving a traditional culture against the material income of the people whose culture it is, or to weigh the value of biodiversity against human wellbeing. Some economists claim that one person’s wellbeing cannot be weighed against another’s (Robbins, 1937; Arrow, 1963). When values cannot be determinately weighed, they are said to be ‘incommensurable’ or ‘incomparable’ (Chang, 1997). Multi-Criteria Analysis (MCA) (discussed in Subsection 3.7.2.1) is a technique that is designed to take account of several incommensurable values (De Montis et al., 2005; Zeleny and Cochrane, 1982).

3.4.1 Non-human values

Nature provides great benefits to human beings, in ways that range from absorbing our waste, to beautifying the world we inhabit. An increasing number of philosophers have argued in recent years that nature also has value in its own right, independently of its benefits to human beings (Leopold, 1949; Palmer, 2011). They have argued that we should recognize animal values, the value of life itself and even the value of natural systems and nature itself.

In moral theory, rational adult humans, who are self-conscious subjects of a life, are often taken (following Kant, 1956) to have a kind of unconditional moral worth – sometimes called 'dignity' – that is not found elsewhere on earth. Others believe that moral worth can be found elsewhere (Dryzek, 1997). Many human beings themselves lack rationality or subjectivity, yet still have moral worth – the very young, the very old and people with various kinds of impairment among them. Given that, why deny moral worth to those animals that are to some extent subjects of a life, who show emotional sophistication (Regan, 2004), and who experience pleasure, pain, suffering and joy (Singer, 1993)?

An argument for recognizing value in plants as well as animals was proposed by Richard Routley (1973). Routley gives the name 'human chauvinism' to the view that humans are the sole possessors of intrinsic value. He asks us to imagine that the last man on earth sets out to destroy every living thing, animal or plant. Most people believe this would be wrong, but human chauvinists are unable to explain why. Human chauvinism appears to be simply a prejudice in favour of the human species (Routley and Routley, 1980). In contrast, some philosophers argue that value exists in the lives of all organisms, to the extent that they have the capacity to flourish (Taylor, 1986; Agar, 2001).

Going further, other philosophers have argued that biological communities and holistic ecological entities also have value in their own right. Some have argued that a species has more value than all of its individuals have together, and that an ecosystem has still more value (Rolston, 1988, 1999; compare discussion in Brennan and Lo, 2010). It has further been proposed that, just as domination of one human group by another is a moral evil, showing disrespect for the value of others, then so is the domination of nature by humans in general. If nature and its systems have moral worth, then the domination of nature is also a kind of disrespect (Jamieson, 2010).

If animals, plants, species and ecosystems do have value in their own right, then the moral impact of climate change cannot be gauged by its effects on human beings alone. If climate change leads to the loss of environmental diversity, the extinction of plant and animal species, and the suffering of animal populations, then it will cause great harms beyond those it does to human beings. Its effects on species numbers, biodiversity and ecosystems may persist for a very long time, perhaps even longer than the lifetime of the human species (Nolt, 2011).

It is very difficult to measure non-human values in a way that makes them commensurate with human values. Economists address this issue by dividing value into use value (associated with actual use of nature – instrumental value) and nonuse or existence value (intrinsic value of nature). As an example, biodiversity might have value because of the medical drugs which might be discovered among the diverse biota (use value). Or biodiversity might be valued by individuals simply because they believe that biologic diversity is important, over and above any use to people that might occur. The total amount people are willing to pay has sometimes been used as an economic measure of the total value (instrumental and intrinsic) of these features (Aldred, 1994). As the discussion of the past few paragraphs has suggested, nature may have additional value, over and above the values placed by individual humans (Broome, 2009; Spash et al., 2009).

3.4.2 Cultural and social values

The value of human wellbeing is considered in Subsection 3.4.3 , but the human world may also possess other values that do not form part of the wellbeing of individual humans. Living in a flourishing culture and society contributes to a person's wellbeing (Kymlicka, 1995; Appiah, 2010), but some authors claim that cultures and societies also possess values in their own right, over and above the contribution they make to wellbeing (Taylor, 1995). Climate change threatens damage to cultural artefacts and to cultures themselves (Adger et al., 2012). Evidence suggests that it may already be damaging the culture of Arctic indigenous peoples (Ford et al., 2006, 2008; Crate, 2008; Hassol, 2004; see also WGII Chapter 12). Cultural values and indigenous peoples are discussed in Subsection 3.10.2 .

The degree of equality in a society may also be treated as a value that belongs to a society as a whole, rather than to any of the individuals who make up the society. Various measures of this value are available, including the Gini coefficient and the Atkinson measure (Gini, 1912; Atkinson, 1970); for an assessment see (Sen, 1973). Section 3.5 explains that the value of equality can alternatively be treated as a feature of the aggregation of individual people's wellbeings, rather than as social value separate from wellbeing.

3.4.3 Wellbeing

Most policy concerned with climate change aims ultimately at making the world better for people to live in. That is to say, it aims to promote people's wellbeing. A person's wellbeing, as the term is used here, includes everything that is good or bad for the person − everything that contributes to making her life go well or badly. What things are those – what constitutes a person's wellbeing? This question has been the subject of an extensive literature since ancient times.[7] One view is that a person's wellbeing is the satisfaction of her preferences. Another is that it consists in good feelings such as pleasure. A third is that wellbeing consists in possessing the ordinary good things of life, such as health, wealth, a long life, and participating well in a good community. The 'capabilities approach' in economics (Sen, 1999) embodies this last view. It treats the good things of life as 'functionings' and 'capabilities' – things that a person does and things that she has a real opportunity of doing, such as living to old age, having a good job and having freedom of choice.

A person's wellbeing will be affected by many of the other values that are mentioned above, and by many of the considerations of justice mentioned in Section 3.3 . It is bad for a person to have her rights infringed or to be treated unfairly, and it is good for a person to live within a healthy culture and society, surrounded by flourishing nature.

Various concrete measures of wellbeing are in use (Fleurbaey, 2009; Stiglitz et al., 2009). Each reflects a particular view about what wellbeing consists in. For example, many measures of 'subjective wellbeing' (Oswald and Wu, 2010; Kahneman and Deaton, 2010) assume that wellbeing consists in good feelings. Monetary measures of wellbeing, which are considered in Section 3.6 , assume that wellbeing consists in the satisfaction of preferences. Other measures assume wellbeing consists in possessing a number of specific good things. The Human Development Index (HDI) is intended to be an approximate measure of wellbeing understood as capabilities and functionings (UNDP, 2010). It is based on three components: life expectancy, education and income. The capabilities approach has inspired other measures of wellbeing too (Dervis and Klugman, 2011). In the context of climate change, many different metrics of value are intended to measure particular components of wellbeing: among them are the numbers of people at risk from hunger, infectious diseases, coastal flooding, or water scarcity. These metrics may be combined to create a more general measure. Schneider et al. (2000) advocates the use of a suite of five metrics: (1) monetary loss, (2) loss of life, (3) quality of life (taking account of forced migration, conflict over resources, cultural diversity and loss of cultural heritage sites), (4) species or biodiversity loss, and (5) distribution and equity.

[7] For example: Aristotle, *Nicomachean Ethics*. Recent work includes: Griffin (1986); Sumner (1999); Kraut (2007).

3.4.4 Aggregation of wellbeing

Whatever wellbeing consists of, policy making must take into account the wellbeing of everyone in the society. So the wellbeings of different people have somehow to be aggregated together. How do they combine to make up an aggregate value of wellbeing for a society as a whole? Social choice theory takes up this problem (Arrow, 1963; Sen, 1970). Section 3.6 will explain that the aim of economic valuation is to measure aggregate wellbeing.

Assume that each person has a level of wellbeing at each time she is alive, and call this her 'temporal wellbeing' at that time. In a society, temporal wellbeing is distributed across times and across the people. When a choice is to be made, each of the options leads to a particular distribution. Our aim is to assess the value of such distributions. Doing so involves aggregating wellbeings across times and across people, to arrive at an overall, social value for the distribution.

3.4.5 Lifetime wellbeing

Next let us assume that each person's temporal wellbeings can be aggregated to determine a 'lifetime wellbeing' for the person, and that the social value of the distribution depends only on these lifetime wellbeings. This is the assumption that each person's wellbeing is 'separable', to use a technical term. It allows us to split aggregation into two steps. First, we aggregate each person's temporal wellbeings across the times in her life in order to determine her lifetime wellbeing. The second step in the next subsection is to aggregate across individuals using a social welfare function.

On one account, a person's lifetime wellbeing is simply the total of her temporal wellbeings at each time she is alive. If a person's wellbeing depended only on the state of her health, this formula would be equivalent to 'qalys' or 'dalys' (quality-adjusted life years or disability-adjusted life years), which are commonly used in the analysis of public health (Murray, 1994; Sassi, 2006). These measures take a person's lifetime wellbeing to be the total number of years she lives, adjusted for her health in each year. Since wellbeing actually depends on other things as well as health, qalys or dalys provide at best an approximate measure of lifetime wellbeing. If they are aggregated across people by simple addition, it assumes implicitly that a year of healthy life is equally as valuable to one person as it is to another. That may be an acceptable approximation for the broad evaluation of climate change impacts and policies, especially for evaluating their effects on health (Nord et al., 1999; Mathers et al., 2009; but also see Currie et al., 2008).

Other accounts give either increasing, (Velleman, 1991) or alternatively decreasing, (Kaplow et al., 2010) weight to wellbeing that comes in later years of life, in determining a person's lifetime wellbeing.

3.4.6 Social welfare functions

Once we have a lifetime wellbeing for each person, the next step is to aggregate these lifetime wellbeings across people, to determine an overall value for society. This involves comparing one person's wellbeing with another's. Many economists have claimed that interpersonal comparisons of wellbeing are impossible.[8] If they are right, the wellbeings of different people are incommensurable and cannot be aggregated. In this Section we set this view aside, and assume that temporal wellbeings are measured in a way that is comparable across people.[9] This allows us to aggregate

[8] Examples are: Robbins (1937), Archibald (1959), Arrow (1963). A survey and discussion of this sceptical view appears in Hammond (1993).

[9] Potential bases of interpersonal comparisons are examined in: Fleurbaey and Hammond (2004); Sen (1982); Elster and Roemer (1993); Mirrlees (1982); Broome, (2004); Arrow (1977); Harsanyi (1977); Adler (2011).

different people's lifetime wellbeings through a social welfare function (SWF) to arrive at an overall value or 'social welfare'.[10]

We shall first consider SWFs under the simplifying but unrealistic assumption that the decisions that are to be made do not affect how many people exist or which people exist: all the options contain the same people. A theorem of Harsanyi's (1955) gives some grounds for thinking that, given this assumption, the SWF is additively separable between people. This means it has the form:

Equation 3.4.1. $V = v_1(w_1) + v_2(w_2) + \ldots + v_J(w_J)$.

Here w_i is person i's lifetime wellbeing. This formula says that each person's wellbeing can be assigned a value $v_i(w_i)$, and all these values – one for each person – are added up to determine the social value of the distribution.

The proof of Harsanyi's Theorem depends on assumptions that can be challenged (Diamond, 1967; Broome, 2004; Fleurbaey, 2010). So, although the additively separable form shown in Equation 3.4.1 is commonly assumed in economic valuations, it is not entirely secure. In particular, this form makes it impossible to give any value to equality except indirectly through prioritarianism, which was introduced in Subsection 3.3.2 and is defined below. The value of inequality cannot be measured by the Gini coefficient, for example, since this measure is not additively separable (Sen, 1973).

It is often assumed that the functions $v_i()$ all have the same form, which means that each person's wellbeing is valued in the same way:

Equation 3.4.2. $V = v(w_1) + v(w_2) + \ldots + v(w_J)$

Alternatively, the wellbeing of people who live later is sometimes discounted relative to the wellbeing of people who live earlier; this implies that the functional form of $v_i()$ varies according to the date when people live. Discounting of later wellbeing is often called 'pure' discounting. It is discussed in Subsection 3.6.2 .

Even if we accept Equation 3.4.2, different ethical theories imply different SWFs. Utilitarianism values only the total of people's wellbeing. The SWF may be written:

Equation 3.4.3. $V = w_1 + w_2 + \ldots + w_J$

Utilitarianism gives no value to equality in the distribution of wellbeing: a given total of wellbeing has the same value however unequally it is distributed among people.

But the idea of distributive justice mentioned in Subsection 3.3.3 suggests that equality of wellbeing does have value. Equation 3.4.2 will give value to equality if the function $v()$ is strictly concave. This means the graph of $v()$ curves downwards, as Figure 3.1 illustrates. (Subsection 3.6.1.1 explains that a person's wellbeing w_i is commonly assumed to be a strictly concave function of her consumption, but this is a different point.) The resulting ethical theory is called prioritarianism. As Figure 3.1 shows, according to prioritarianism, improving a *person's* wellbeing contributes more to social welfare if the person is badly off than if she is well off. The prioritarian slogan is 'priority to the worse off'. Prioritarianism indirectly gives value to equality: it implies that a given total of wellbeing is more valuable the more equally it is distributed (Sen, 1973; Weirich, 1983; Parfit, 1997). In judgements about climate change, a prioritarian function will give relatively more importance to the interests of poorer people and poorer countries.

[10] A recent major study is Adler (2011).

Figure 3.1. The prioritarian view of social welfare. The figure compares the social values of increases in wellbeing for a better-off and a worse-off person.

3.4.7 Valuing population

The next problem in aggregating wellbeing is to take account of changes in population. Climate change can be expected to affect the world's human population. Severe climate change might even lead to a catastrophic collapse of the population (Weitzman, 2009), and even to the extinction of human beings. Any valuation of the impact of climate change and of policies to mitigate climate change should therefore take changes in population into account.

The utilitarian and prioritarian SWFs for a fixed population may be extended in a variety of ways to a variable population. For example, the utilitarian function may be extended to 'average utilitarianism' (Hurka, 1982), whose SWF is the average of people's wellbeing. Average utilitarianism gives no value to increasing numbers of people. The implicit or explicit goal of a great deal of policy-making is to promote per capita wellbeing (Hardin, 1968). This is to adopt average utilitarianism. This goal tends to favour anti-natalist policies, aimed at limiting population. It would strongly favour population control as a means of mitigating climate change, and it would not take a collapse of population to be, in itself, a bad thing.

The utilitarian function may alternatively be extended to 'critical-level utilitarianism', whose SWF is the total of the amount by which each person's wellbeing exceeds some fixed critical level. It is

Equation 3.4.4. $V = (w_1 - c) + (w_2 - c) + \ldots + (w_J - c)$

where c is the critical level (Broome, 2004; Blackorby et al., 2005). Other things being equal, critical-level utilitarianism favours adding people to the population if their wellbeing is above the critical level.

'Total utilitarianism' (Sidgwick, 1907) is critical-level utilitarianism with the critical level set to zero. Its SWF is the total of people's wellbeing. Total utilitarianism is implicit in many Integrated Assessment Models (IAMs) of climate change (e.g., Nordhaus, 2008). Its meaning is indeterminate until it is settled which level of lifetime wellbeing to count as zero. Many total utilitarians set the zero at the level of a life that has no good or bad experiences – that is lived in a coma throughout, for instance (Arrhenius, forthcoming). Since people on average lead better lives than this, total utilitarianism with this zero tends to be less anti-natalist than average utilitarianism. However, it does not necessarily favour increasing population. Each new person damages the wellbeing of existing people, through her emissions of GHG, her other demands on Earth's limited resources, and the emissions of her progeny. If the damage an average person does to others in total exceeds her own wellbeing, total utilitarianism, like average utilitarianism, favours population control as a means of mitigating climate change.[11]

Each of the existing ethical theories about the value of population has intuitively unattractive implications (Parfit, 1986). Average utilitarianism is subject to particularly severe objections. Arrhenius (forthcoming) crystallizes the problems of population ethics in the form of impossibility theorems. So far, no consensus has emerged about the value of population. Yet climate-change policies are expected to affect the size of the world's population, and different theories of value imply very different conclusions about the value of these policies. This is a serious difficulty for evaluating policies aimed at mitigating climate change, which has largely been ignored in the literature (Broome, 2012).

3.5 Economics, rights and duties

Sections 3.2 , 3.3 and 3.4 have outlined some of the ethical principles that can guide decision-making for climate change. The remainder of this Chapter is largely concerned with the concepts and methods of economics. They can be used to aggregate values at different times and places, and weigh aggregate value for different policy actions. They can also be used to draw information about value from the data provided by prices and markets. Economics can measure diverse benefits and harms, taking account of uncertainty, to arrive at overall judgements of value. It also has much to contribute to the choice and design of policy mechanisms, as Section 3.8 and later chapters show.

Valuations provided by economics can be used on a large scale: IAMs can be used to simulate the evolution of the world's economy under different climate regimes and determine an economically efficient reduction in GHG emissions. On a smaller scale, economic methods of CBA can be used in choosing between particular policies and technologies for mitigation.

Economics is much more than a method of valuation. For example, it shows how decision making can be decentralized through market mechanisms. This has important applications in policy instruments for mitigation with potential for cost-effectiveness and efficiency (Chapters 6 and 15). Economic analysis can also give guidance on how policy mechanisms for international cooperation on mitigation can be designed to overcome free-rider problems (Chapters 13 and 14). However, the methods of economics are limited in what they can do. They can be based on ethical principles, as Section 3.6 explains. But they cannot take account of every ethical principle. They are suited to measuring and aggregating the wellbeing of humans, but not to taking account of justice and rights (with the exception of distributive justice − see below), or other values apart from human wellbeing. Moreover, even in measuring and aggregating wellbeing, they depend on certain specific ethical assumptions. This Section describes the limits of economic methods.

Because of their limitations, economic valuations are often not on their own a good basis for decision making. They frequently need to be supplemented by other ethical considerations. It is then appropriate to apply techniques of multi-criteria analysis (MCA), discussed in Subsection 3.7.2.1 (Zeleny and Cochrane, 1982; Keeney and Raiffa, 1993; De Montis et al., 2005).

3.5.1 Limits of economics in guiding decision making

Economics can measure and aggregate human wellbeing, but Sections 3.2 , 3.3 and 3.4 explain that wellbeing may be only one of several criteria for choosing among alternative mitigation policies.

[11] Harford (1998) shows that an additional person causes damage from her own emissions and the emissions of her children (and of their children, etc.). Kelly and Kolstad (2001) examine this issue in the specific context of climate change.

Other ethical considerations are not reflected in economic valuations, and those considerations may be extremely important for particular decisions that have to be made. For example, some have contended that countries that have emitted a great deal of GHG in the past owe restitution to countries that have been harmed by their emissions. If so, this is an important consideration in determining how much finance rich countries should provide to poorer countries to help with their mitigation efforts. It suggests that economics alone cannot be used to determine who should bear the burden of mitigation.

What ethical considerations can economics cover satisfactorily? Since the methods of economics are concerned with value, they do not take account of justice and rights in general. However, distributive justice can be accommodated within economics, because it can be understood as a value: specifically the value of equality. The theory of fairness within economics (Fleurbaey, 2008) is an account of distributive justice. It assumes that the level of distributive justice within a society is a function of the wellbeings of individuals, which means it can be reflected in the aggregation of wellbeing. In particular, it may be measured by the degree of inequality in wellbeing, using one of the standard measures of inequality such as the Gini coefficient (Gini, 1912), as discussed in the previous Section. The Atkinson measure of inequality (Atkinson, 1970) is based on an additively separable SWF, and is therefore particularly appropriate for representing the prioritarian theory described in Subsection 3.4.6 . Furthermore, distributive justice can be reflected in weights incorporated into economic evaluations as Section 3.6 explains.

Economics is not well suited to taking into account many other aspects of justice, including compensatory justice. For example, a CBA might not show the drowning of a Pacific island as a big loss, since the island has few inhabitants and relatively little economic activity. It might conclude that more good would be done in total by allowing the island to drown: the cost of the radical action that would be required to save the island by mitigating climate change globally would be much greater than the benefit of saving the island. This might be the correct conclusion in terms of overall aggregation of costs and benefits. But the island's inhabitants might have a right not to have their homes and livelihoods destroyed as a result of the GHG emissions of richer nations far away. If that is so, their right may override the conclusions of CBA. It may give those nations who emit GHG a duty to protect the people who suffer from it, or at least to make restitution to them for any harms they suffer.

Even in areas where the methods of economics can be applied in principle, they cannot be accepted without question (Jamieson, 1992; Sagoff, 2008). Particular simplifying assumptions are always required, as shown throughout this Chapter. These assumptions are not always accurate or appropriate, and decision-makers need to keep in mind the resulting limitations of the economic analyses. For example, climate change will shorten many people's lives. This harm may in principle be included within a CBA, but it remains highly contentious how that should be done. Another problem is that, because economics can provide concrete, quantitative estimates of some but not all values, less quantifiable considerations may receive less attention than they deserve.

The extraordinary scope and scale of climate change raises particular difficulties for economic methods (Stern, forthcoming). First, many of the common methods of valuation in economics are best designed for marginal changes, whereas some of the impacts of climate change and efforts at mitigation are not marginal (Howarth and Norgaard, 1992). Second, the very long time scale of climate change makes the discount rate crucial at the same time as it makes it highly controversial (see Subsection 3.6.2). Third, the scope of the problem means it encompasses the world's extremes of wealth and poverty, so questions of distribution become especially important and especially difficult. Fourth, measuring non-market values – such as the existence of species, natural environments, or traditional ways of life of local societies – is fraught with difficulty. Fifth, the uncertainty that surrounds climate change is very great. It includes the likelihood of irreversible changes to societies and to nature, and even a small chance of catastrophe. This degree of uncertainty sets special problems for economics (Nelson, 2013).

Box 3.2 Who mitigates versus who pays?

To mitigate climate change, emissions of GHG will need to be reduced to a greater or lesser extent world-wide. Economic analysis tells us that, for the sake of cost-effectiveness, the greatest reductions should be made where they can be made most cheaply. Ideally, emissions should be reduced in each place to just the extent that makes the marginal cost of further reductions the same everywhere. One way of achieving this result is to have a carbon price that is uniform across the world; or it might be approximated by a mix of policy instruments (see Section 3.8).

Since, for efficiency, mitigation should take place where it is cheapest, emissions of GHG should be reduced in many developing countries, as well as in rich ones. However, it does not follow that mitigation must be paid for by those developing countries; rich countries may pay for mitigation that takes place in poor countries. Financial flows between countries make it possible to separate the question of where mitigation should take place from the question of who should pay for it. Because mitigating climate change demands very large-scale action, if put in place these transfers might become a significant factor in the international distribution of wealth. Provided appropriate financial transfers are made, the question of where mitigation should take place is largely a matter for the economic theory of efficiency, tempered by ethical considerations. But the distribution of wealth is a matter of justice among countries, and a major issue in the politics of climate change (Stanton, 2011).

It is partly a matter of distributive justice, which economics can take into account, but compensatory justice may also be involved, an issue for ethics (Section 3.3).

3.6 Aggregation of costs and benefits

3.6.1 Aggregating individual wellbeing

Policies that respond to climate change almost always have some good and some bad effects; we say they have 'benefits' and 'costs'. In choosing a policy, we may treat one of the available options as a standard of comparison – for instance, the status quo. Other options will have costs and benefits relative to this standard. Most mitigation strategies have costs in the present and yield benefits in the future. Policy-making involves assessing the values of these benefits and costs and weighing them against each other. Chapter 6 contains an example in which different mitigation strategies yielding different temporal allocations of climate impacts are compared. The weighing of costs and benefits need not be a precise process. Sections 3.2 and 3.4 explain that costs and benefits may be values of very different sorts, which cannot be precisely weighed against each other. They may also be very uncertain.

Nevertheless, the discipline of economics has developed methods for measuring numerically values of one particular sort: human wellbeing. In this Section, we describe these methods; Section 3.5 explains their serious limitations. Economists often use money as their unit of measurement for values, but not always. In health economics, for example, the unit of benefit for health care is often the 'quality-adjusted life year' (qaly) (see Box 3.3). In economics, monetary measures of value are used in cost-effectiveness analysis (see Weimer and Vining, 2010), in estimating the social cost of carbon (see Subsection 3.9.4), in inter-temporal optimization within IAMs (e.g., Stern, 2007; Nordhaus, 2008), in CBA and elsewhere.

Generally the overall value of aggregate wellbeing needs to be measured, and not merely the wellbeing of each individual. A numerical measure of overall wellbeing may be based on ethical analysis, through a SWF of the sort introduced in Section 3.4 . This basis of valuation is described here. The literature contains a putative alternative basis built on the 'potential Pareto criterion', but this is subject to severe objections (De Scitovszky, 1941; Gorman, 1955; Arrow, 1963, ch. 4; Boadway and Bruce, 1984; Blackorby and Donaldson, 1990).

We take as our point of departure the formulation of the SWF in Equation 3.4.2, which is based on assumptions described in Subsection 3.4.6. To these we now add a further assumption that times are separable, meaning that the distribution of wellbeing can be evaluated at each time separately and its overall value is an aggregate of these separate 'snap-shot' values. A theorem of Gorman's (1968) ensures that social welfare then takes the fully additively separable form:

Equation 3.6.1. $V = \delta_1 V_1 + \delta_2 V_2 + \ldots + \delta_T V_T$

where each V_t is the value of wellbeing at time t and is the total of the values of individual wellbeings at that time. That is:

Equation 3.6.2. $V_t = v(w_{1t}) + v(w_{2t}) + \ldots + v(w_{It})$.

Each w_{it} is the temporal wellbeing of person i at time t. Each δ_t is a 'discount factor', which shows how wellbeing at time t is valued relative to wellbeing at other times.

The assumption that times are separable has some unsatisfactory consequences. First, it cannot give value to equality between people's lives taken as a whole, but only to equality at each particular time. Second, Equation 3.6.1 is inconsistent with average utilitarianism, or with valuing per capita temporal wellbeing at any time, whereas per capita wellbeing is a common object of climate-change policy. Third, Equation 3.6.1 makes no distinction between discounting within a single person's life and intergenerational discounting. Yet a case can be made for treating these two sorts of discounting differently (Kaplow et al., 2010). Nevertheless, this assumption and the resulting equation Equation 3.6.1 underlies the usual practice of economists when making valuations. First they aggregate temporal wellbeing across people at each time to determine a snap-shot social value for each time. Then all these values are aggregated across times. This Section and the next describe the usual practice based on these equations.[12] The second step − aggregation across time − is considered in Subsection 3.6.1 . The rest of this Section considers the first step − aggregation at time.

3.6.1.1 Monetary values

Climate policies affect the wellbeing of individuals by changing their environment and their individual consumption. The first step in a practical economic valuation is to assign a monetary value to the costs and benefits that come to each person at each time from the change. This value may be either the amount of money the person is willing to pay for the change, or the amount she is willing to accept as compensation for it. If the change is a marginal increase or decrease in the person's consumption of a marketed commodity, it will be equal to the price of the commodity.

The effect of a change on the person's wellbeing is the monetary value of the change multiplied by the rate at which money contributes to the person's wellbeing. This rate is the marginal benefit of money or marginal utility of money to the person. It is generally assumed to diminish with increasing income (Marshall, 1890; Dalton, 1920; Pigou, 1932, p. 89; Atkinson, 1970).

The effects of the change on each person's wellbeing at each time must next be aggregated across people to determine the effect on social value. Equation 3.6.2 shows how each person's wellbeing contributes to social value through the value function v(). The change in wellbeing must therefore be multiplied by the marginal social value of wellbeing, which is the first derivative of this function. It is an ethical parameter. According to utilitarianism, it is constant and the same for everyone. According to prioritarianism, it diminishes with increasing wellbeing.

[12] An alternative approach does not assume separability of times. First it determines a lifetime wellbeing for each person in the way described in Subsection 3.4.5 . For instance, *i*'s lifetime wellbeing might be a discounted total of her temporal wellbeings. Then this approach aggregates across people using Equation 3.4.2. See Fullerton and Rogers (1993), Murphy and Topel (2006) and Kaplow et al. (2010).

In sum, the effect of a change in social value at a particular time is calculated by aggregating the monetary value of the change to each person, weighted by the social marginal value of money to the person, which is the product of the marginal benefit of money to her and the marginal social value of her wellbeing (Fleurbaey, 2009). Since the marginal benefit of money is generally assumed to diminish with increasing income, the marginal social value of money can be assumed to do the same.

Many practical CBAs value costs and benefits according to aggregated monetary values without any weighting. The implicit assumption is that the marginal social value of money is the same for each person. The consequence of omitting weights is particularly marked when applying CBA to climate change, where extreme differences in wealth between rich and poor countries need to be taken into account. An example appeared in the Second Assessment Report of the IPCC (1995), where it considered the value of human life (see Box 3.3). The Report showed that the effect of ignoring weighting factors would be to assign perhaps twenty times more value to an American life than to an Indian life. Even within a single country, weighting makes a big difference. Drèze (1998) examines the benefits of reducing pollution in Delhi and contrasts New Delhi, which is relatively rich, with Delhi, which is relatively poorer. If the criterion is reducing pollution for the greatest number of people, then projects in Delhi will be favoured; whereas projects in New Delhi will be favoured if the criterion is unweighted net benefits.

Box 3.3 The value of life.

Climate change may shorten many people's lives, and mitigating climate change may extend many people's lives. Lives must therefore be included in any CBA that is concerned with climate change. The literature contains two different approaches to valuing a person's life. One is based on the length of time the person gains if her life is saved, adjusted according to the quality of her life during that time. This gives a measure of the value of life known as the qaly (Sassi, 2006, pp. 402–408), widely used to value lives in health economics and public health. For assessing the impact of climate on human health and longevity, the World Health Organization uses the 'disability-adjusted life year' (daly), which is similar (Mathers et al., 2009; for dalys see, Murray, 1994).

The other approach values the extension of a person's life on the basis of what she would be willing to pay for it. In practice, this figure is usually derived from what she would be willing to pay for an increased chance of having an extended life. If, say, a person is willing to pay $100 to reduce her chance of dying in a road accident from 2 in 10,000 to 1 in 10,000, then her willingness to pay (WTP) for extending her life is $100 x 10,000 = $1 million. A WTP measure of the value of life is widely used in environmental economics (e.g., U.S. Environmental Protection Agency, 2010 Appendix B); it is often known as a 'value of statistical life' (Viscusi and Aldy, 2003).

The main differences between these approaches are:

1. Since WTP is measured in money, it is immediately comparable with other values measured in money. Qalys need to be assigned a monetary value to make them comparable (Mason et al., 2009).

2. The use of qalys implies a theoretical assumption about the value of extending a life – that it is proportional to the length of the extension, adjusted for quality – whereas WTP methods generally leave it entirely to the individual to set a value on extending her own life (Broome, 1994).

3. Each measure implies a different basis for interpersonal comparisons of value. When qalys are aggregated across people by addition, the implicit assumption is that a year of healthy life has the same value for each person. When WTP is aggregated across people by addition (without distributional weights), the implicit assumption is that a dollar has the same value for each

person. Neither assumption is accurate, but for comparisons involving very rich countries and very poor ones, the former seems nearer the truth (Broome, 2012, ch. 9).

The two approaches can converge. The text explains that distributional weights should be applied to monetary values before they are aggregated, and this is true of WTP for extending life. If appropriate weights are applied, WTP becomes more nearly proportional to qalys. Indeed, if we adopt the assumption that a qaly has the same value for each person, we may use it to give us a basis for calculating distributional weights to apply to money values (Somanathan, 2006). For example, suppose WTP for a 30-year extension to healthy life in the United States is $5 million, and in India it is $250,000; then, on this assumption, $1 to an Indian has the same value as $20 to an American.

Another example of a monetary measure of value that does not incorporate distributional weights is GDP. To evaluate changes by their effect on GDP is, once again, to assume that the value of a dollar to a rich person is the same as its value to a poor person (Schneider et al., 2000).

It is sometimes assumed that CBA is conducted against the background of efficient markets and an optimal redistributive taxation system, so that the distribution of income can be taken as ideal from society's point of view. If that were true, it might remove the need for distributional weights. But this is not an acceptable assumption for most projects aimed at climate change. Credit and risk-sharing markets are imperfect at the world level, global coordination is limited by agency problems, information is asymmetric, and no supra-national tax authority can reduce worldwide inequalities. Furthermore, intergenerational transfers are difficult. In any case, the power of taxation to redistribute income is limited because redistributive taxes create inefficiency (Mirrlees, 1971). Even optimal taxation would therefore not remove the need for distributional weights. Thus, the assumption that incomes are (second-best) optimally redistributed does not neutralize the argument for welfare weights in aggregating costs and benefits.

The need for weights makes valuation more complicated in practice. The data available for costs and benefits is generally aggregated across people, rather than separated for particular individuals. This means that weights cannot be applied directly to individuals' costs and benefits, as they ideally should be. This difficulty can be overcome by applying suitably calculated weights to the prices of commodities, calculated on the basis of income distribution of each commodity's consumers.[13]

Box 3.4 Optimality versus Pareto improvement in climate change

The assessment of a change normally requires benefits to be weighed against costs. An exception is a change − known as a 'Pareto improvement' − that benefits some people without harming anyone. Climate change provides one possible example. GHG is an externality: a person whose activities emit GHG does not bear the full cost of her activities; some of the costs are borne by those who are harmed by the emissions. Consequently, climate change causes Pareto inefficiency, which means that a Pareto improvement would in principle be possible. Indeed it would be possible to remove the inefficiency in a way that requires no sacrifice by anyone in any generation, compared to Business-As-Usual. To achieve this result, the present generation must reallocate investment towards projects that reduce emissions of GHG, while maintaining its own consumption. Because it maintains its own consumption, it makes no sacrifice. Because it reduces its conventional investment, it bequeaths less conventional capital to future generations. Other things being equal, this would make future generations less well off, but the reduction in emissions will more than compensate them for that loss (Stern, forthcoming; Foley, 2009; Rezai et al., 2011).

[13] The method is presented in Drèze and Stern (1989, pp. 909–989). Applications of distributional weights to climate change appear in Azar and Sterner (1996); and Fankhauser et al. (1997).

It is commonly assumed that climate change calls for sacrifices by the present generation for the sake of future generations. The diagram illustrates why. The possibility frontier shows what combinations of consumption are possible for present and future generations. Because of the externality, Business-As-Usual lies below this frontier. The frontier can be reached by a Pareto improvement. Contours of two different SWFs are shown. One SWF places more value than the other on future consumption relative to present consumption. The two contours reflect in a purely illustrative way SWFs that are implicit in Stern (2007) and Nordhaus (2008) respectively. The point where a contour touches the possibility frontier is the social optimum according to that function. Neither optimum is a Pareto improvement on Business as Usual. Although the inefficiency could be removed without any sacrifices, the best outcomes described by both Stern and Nordhaus do require a sacrifice by the present generation.

From an international rather than an intergenerational perspective, it is also true on the same grounds that the inefficiency of climate change can be removed without any nation making a sacrifice (Posner and Weisbach, 2010). But it does not follow that this would be the best outcome.

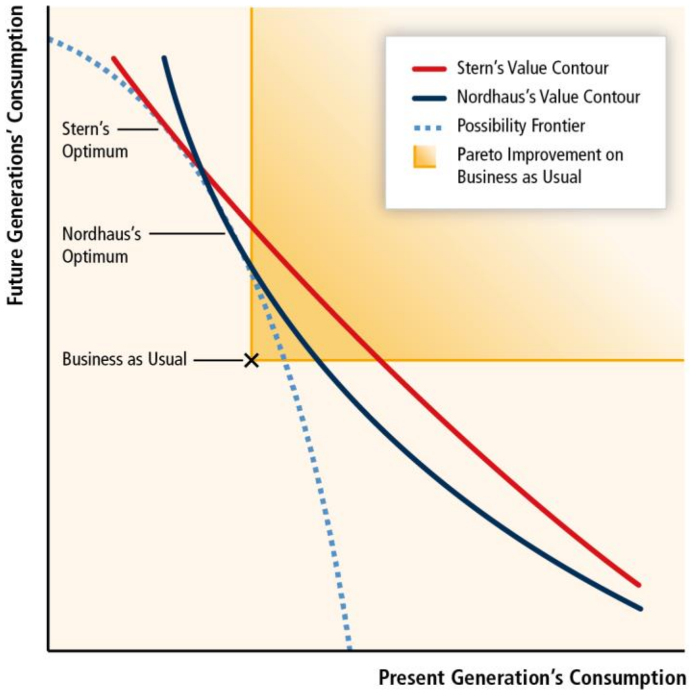

Figure 3.2. Illustrating optimality versus Pareto improvement in climate change**.**

3.6.2 Aggregating costs and benefits across time

In climate change decisions, aggregating the pros and cons of alternative actions is particularly difficult because most benefits of mitigation will materialize only in the distant future. On the other hand, the costs of mitigation are borne today. Using a discount rate can therefore make a big difference in evaluating long-term projects or investments for climate change mitigation. For example, a benefit of $1 million occurring in 100 years has a present value of $369,000 if the discount rate is 1%, $52,000 if it is 3%, and $1,152 if it is 7%. An important debate in economics since AR4, spawned in part by the Stern (2007) Review, has centred on the discount rate that should be applied in evaluating climate change impacts and mitigation costs (Nordhaus, 2007; Stern, 2008; Dasgupta, 2008; Smith, 2010; see also Quiggin, 2008).

A descriptive approach to discounting examines how human beings trade-off the present against their own futures. It focuses on how individuals and markets make inter-temporal financial decisions, as revealed by the market interest rate. A simple arbitrage argument favours using the interest rate as the discount rate for climate policy decisions: if one reallocates capital from a safe but marginal project (whose return must be equal to the interest rate) to a safe project with the same maturity whose return is smaller than the interest rate, the net impact is null for the current generation, and is negative for future generations. Thus, when projects are financed by a reallocation of capital rather than an increase in aggregate saving (reducing consumption), the discount rate should be equal to the shadow cost of capital.

Table 3.1 documents real returns on different classes of assets in western countries, including government bonds, which are usually considered to be the safest, most risk-free assets. As can be seen, these rates are close to zero.

Table 3.1: Real returns of financial assets. Source: Updated data from (Dimson, 2002), in Gollier (2012).

	Government Bills (maturity <1 year)		Government Bonds (maturity =10 years)		Equity	
	1900-2006	1971-2006	1900-2006	1971-2006	1900-2006	1971-2006
Australia	0.6%	2.5%	1.3%	2.8%	7.8%	6.3%
France	-2.9%	1.2%	-0.3%	6.6%	3.7%	7.8%
Japan	-2.0%	0.4%	-1.3%	3.9%	4.5%	5.0%
United Kingdom	1.0%	1.9%	1.3%	3.9%	5.6%	7.1%
USA	1.0%	1.3%	1.9%	4.0%	6.6%	6.6%

The same arbitrage argument could be used to discount risky projects. In that case, the discount rate should be equal to the expected rate of return of traded assets with the same risk profile. For example, if the project has the same risk profile as a diversified portfolio of equity, one should use the expected rate of return of equity, as documented in

Table 3.1. It contains a relatively large equity premium.

This descriptive approach to the discount rate has many drawbacks. First, we should not expect markets to aggregate preferences efficiently when some agents are not able to trade, as is the case for future generations (Diamond, 1977). Second, current interest rates are driven by the potentially impatient attitude of current consumers towards transferring their *own* consumption to the future. But climate change is about transferring consumption across different people and generations, so that determining the appropriate social discount rate is mostly a normative problem. Thirdly, we do not observe safe assets with maturities similar to those of climate impacts, so the arbitrage argument cannot be applied.

We now examine the problem of a social policy-maker who must make climate policy choices using a SWF discussed earlier. In aggregating damages and costs over time, in order to make things comparable across long periods we value consumption changes in the future by equivalent changes in consumption today. These changes in the structure of consumption should be evaluated in monetary terms using values described in Subsection 3.6.1.1 . The incorporation of the intergenerational equity objective has challenged the traditional CBA approach for the evaluation of climate change policies. Practitioners of CBA and evaluators are expected to use discount rates that are consistent with the pre-specified SWF that represents the society's intergenerational values, as in AR2 (1995). We simplify the model used in Subsection 3.6.1.1 by assuming only one generation per period and only one consumer good. In an uncertain context, an action is socially desirable if it raises the SWF given by Equation 3.6.1:

Equation 3.6.3. $$V = \sum_{t=0}^{\infty} e^{-\delta t} Eu(c_t) ,$$

where $u(c_t) = v(w(c_t)) = V_t$ is the contribution to the SWF of generation t consuming c_t. Because c_t is uncertain, one should take the expectation $Eu(c_t)$ of this uncertain contribution. The concavity of function *u* combines prioritarism (inequality aversion) and risk aversion. Parameter δ measures our collective pure preference for the present, so that the discount factor $d(t) = e^{-\delta t}$ decreases exponentially. δ is an ethical parameter that is not related to the level of impatience shown by individuals in weighting their own future wellbeing (Frederick et al., 2002). Many authors have argued for a rate of zero or near-zero (Ramsey, 1928; Pigou, 1932; Harrod, 1949; Parfit, 1986; Cowen, 1992; Schelling, 1995; Broome, 2004; Stern, 2008). Assuming $\delta>0$ would penalize future generations just because they are born later. Many regard such 'datism' to be as ethically unacceptable as sexism or racism. Cowen (1992) points out that discounting violates the Pareto principle for a person who might live either at one time or at a later time. Some have argued for a positive rate (Dasgupta and Heal, 1980; Arrow, 1999). A traditional argument against a zero rate is that it places an extremely heavy moral burden on the current generation (see, e.g., Dasgupta, 2007). But even when $\delta=0$, as we see below, we still end up with a discount rate of about 4%, which is higher than it was during the last century. Stern (2008) used δ =0.1% to account for risk of extinction. We conclude that a broad consensus is for a zero or near-zero pure rate of time preference for the present.

In a growing economy ($c_t > c_0$), investing for the future in a safe project has the undesirable effect of transferring consumption from the poor (current generations) to the wealthy (future generations). Thus, investing in safe projects raises intergenerational inequalities. The discount rate can then be interpreted as the minimum rate of return that is necessary to compensate for this adverse effect on the SWF of investing for the future. This is summarized by the Ramsey rule (i.e. the consumption approach to discounting) (Ramsey, 1928). Assuming a standard constant elasticity in the consumption utility function (e.g., $u(c)=c^{1-\eta}/(1-\eta)$), and no uncertainty,[14] the minimum rate of return ρ_t of a project that marginally transfers consumption from 0 to t and that guarantees an increase of intergenerational welfare V is defined as follows:

Equation 3.6.4. $\rho_t = \delta + \eta g_t$

where δ represents the pure rate at which society discounts the utility of future generations, and g_t is the annualized growth rate of monetized consumption anticipated at date *t,* and $\eta>0$ measures inequality aversion. The greater the anticipated economic growth rate g_t, the higher the social discount rate ρ_t. The growth rate g_t is an empirical variable that represents our collective beliefs about prospective economic growth. In Box 3.5, we discuss plausible values for the inequality aversion parameter η.

[14] For alternative assumptions, see Gollier (2002) .

Box 3.5 Plausible values for collective inequality aversion (η)

Consider the following thought experiment. A country has two equally populated social groups. The wealthy group consumes twice as many goods and services as the poor group. Consider also an economic policy whose aim is to increase consumption by 1 unit for every person in the poor group. This implies a reduction of consumption for every wealthy person by x units, which may not be equal to 1 owing to inherent inefficiencies in the tax system. If one is neutral about inequalities, one would not accept this policy if x is larger than 1. Inequality aversion justifies accepting some productive inefficiency, so that an x larger than 1 may be allowed. What is the maximum value of x that one would accept to implement the policy? Answering this question tells us something about inequality aversion, with a large x being associated with a larger η. If one is collectively ready to sacrifice as much as x=2 units of consumption from the rich to provide one unit of consumption to the poor, this is compatible with an inequality aversion index η=1. An x of 4 or 8 would correspond to an index of inequality aversion of 2 and 3, respectively.

Behind the veil of ignorance (Rawls, 1971), our collective preferences towards inequality should be identified as our individual risk aversion. The economic literature in finance and macroeconomics usually assumes a η between 1 and 5 to explain observed behaviours towards risk, as well as asset prices (Kocherlakota, 1996).

By using a near-zero time discount rate, the Stern Report (2007, see also 2008) advanced the debate in the literature. Despite disagreement on the empirical approach to estimating the discount rate, the literature suggests consensus for using declining discount rates over time. Different prominent authors and committees have taken different positions on the values of δ, η and g, making different recommendations for the social discount rate ρ. We summarize them in Table 3.2.

Table 3.2. Calibration of the discount rate based on the Ramsey rule (Equation 3.6.4.)

Author	Rate of pure preference for present	Inequality aversion	Growth rate	Implied social discount rate
Cline (1992)	0%	1.5	1%	1.5%
IPCC (1996)	0%	1.5-2	1.6% - 8%	2.4% - 16%
Arrow (1999)	0%	2	2%	4%
UK: Green Book (HM Treasury, 2003)	1.5%	1	2%	3.5%*
US UMB (2003)**				3% - 7%
France: Rapport Lebègue (2005)	0%	2	2%	4%*
Stern (2007)	0.1%	1	1.3%	1.4%
Arrow (2007)		2-3		
Dasgupta (2007)	0.1%	2-4		
Weitzman (2007a)	2%	2	2%	6%
Nordhaus (2008)	1%	2	2%	5%

*Decreasing with the time horizon. **OMB uses a descriptive approach.

In Table 3.2, the Ramsey formula can be seen to yield a wide range of discount rates, although most or all of the estimates reflect developed country experience. From this table and Box 3.5, a relative consensus emerges in favour of δ=0 and η between 1 and 3, although they are prescriptive parameters. This means that the normative Ramsey rule leads to a recommendation for a social discount rate of between one and three times the estimated growth rate in consumption between today and the relevant safe benefit or cost to be discounted. The social discount rate is normative because it relies on the intensity of our collective inequality aversion. However, the practical coherence of our ethical principles requires that if one has high inequality aversion, one should also redistribute wealth more assiduously from the currently rich to the currently poor. Furthermore, it is ultimately a judgement by the policymaker on the appropriate value of the parameters of the Ramsey rule, and thus the social discount rate.

The discount rate described here should be used to discount risk-free costs and benefits (Anthoff et al., 2009). The rates that appear in Table 3.2 are higher than real interest rates observed on financial markets, as documented in

Table 3.1. This discrepancy defines the risk-free rate puzzle (Weil, 1989). The recent literature on discounting has tried to solve this puzzle by taking into account the uncertainty surrounding economic growth. Prudent agents should care more about the future if the future is more uncertain, in line with the concept of sustainable development. Assuming a random walk for the growth rate of consumption per capita, this argument applied to Equation 3.6.4 leads to an extended Ramsey rule in which a negative precautionary effect is added:

Equation 3.6.5. $\rho_t = \delta + \eta g_t - 0.5\ \eta(\eta+1)\sigma_t^2$

where σ_t is the annualized volatility of the growth rate of GDP/cap, and g_t is now the expected annualized growth rate until time horizon t. In Table 3.3, we calibrate this formula for different countries by using the estimation of the trend and volatility parameters of observed growth rates of consumption per capita over the period 1969–2010, using η=2. We learn from this Table that the Ramsey rule (Equation 3.4.1) often provides a good approximation of the social discount rate to be applied to consumption. It also shows that because of differences in growth expectations, nations may have different attitudes towards reducing present consumption for the benefit of future generations. This is also a further source of international disagreement on the strength of GHG mitigation efforts. The global discount rate for evaluating global actions will therefore depend on how costs and benefits are allocated across countries.[15]

Table 3.3. Country-specific discount rate computed from the Ramsey rule (Equation 3.6.5) using the historical mean g and standard deviation σ of growth rates of real GDP/cap 1969-2010, together with $\delta = 0$, and .$\eta = 2$. (Source: Gollier, 2012)

	Country	g	σ	*Discount rate*	
				Ramsey rule Equation 3.6.4	*Extended Ramsey rule Equation 3.6.5*
Developed countries	United States	1.74%	2.11%	3.48%	3.35%
	United Kingdom	1.86%	2.18%	3.72%	3.58%
	Japan	2.34%	2.61%	4.68%	4.48%
Emerging countries	China	7.60%	3.53%	15.20%	14.83%
	India	3.34%	3.03%	6.68%	6.40%
	Russia	1.54%	5.59%	3.08%	2.14%
Africa	Gabon	1.29%	9.63%	2.58%	-0.20%
	Zaire (RDC)	-2.76%	5.31%	-5.52%	-6.37%
	Zambia	-0.69%	4.01%	-1.38%	-1.86%
	Zimbabwe	-0.26%	6.50%	-0.52%	-1.79%

[15] Table 3.3 is based on the assumption that the growth process is a random walk, so that the average growth rate converges to its mean in the very long run. It would be more realistic to recognize that economic growth has a much more uncertain nature in the long run: shocks on growth rates are often persistent, economies faces long-term cycles of uncertain length, and some parameters of the growth process are uncertain. Because these phenomena generate a positive correlation in future annual growth rates, they tend to magnify the uncertainty affecting the wellbeing of distant generations, compared to the random walk hypothesis of the extended Ramsey rule (Equation 3.6.5).

A prudent society should favour actions that generate more benefits for the generations that face greater uncertainty, which justifies a decreasing term structure for risk-free discount rates (Gollier, 2012; Arrow et al., 2013; Weitzman, 2013). These results are related to the literature on Gamma discounting (Weitzman, 1998, 2001, 2010b; Newell and Pizer, 2003; Gollier and Weitzman, 2010). A simple guideline emerging from this literature is that the long-maturity discount rate is equal to the smallest discount rate computed from Equation 3.6.5 with the different plausible levels of its parameters. For example, assuming η=2, if the trend of growth g_t is unknown but somewhere between 1% and 3%, a discount rate around 2 x mean (1%,3%)=4% is socially desirable in the short term, although a discount rate of only 2 x min (1%,3%)=2% is desirable for very long maturities.

Assuming a constant rate of pure preference for the present (actually δ=0), these recommendations yield a perfectly time-consistent valuation strategy, although the resulting discount rates decrease with maturity. A time inconsistency problem arises only if we assume that the rate of pure preference for the present varies according to the time horizon. Economists have tended to focus on hyperbolic discounting and time inconsistency (Laibson, 1997) and the separation between risk aversion and consumption aversion fluctuations over time (Epstein and Zin, 1991). See Subsection 3.10.1 and Chapter 2.

The literature deals mainly with the rate at which safe projects should be discounted. In most cases, however, actions with long-lasting impacts are highly uncertain, something that must be taken into account in their evaluation. Actions that reduce the aggregated risk borne by individuals should be rewarded and those that increase risk should be penalized. This has traditionally been done by raising the discount rate of a project by a risk premium $\pi=\beta\pi_g$ that is equal to the project-specific risk measure β times a global risk premium π_g. The project-specific beta is defined as the expected increase in the benefit of the project when the consumption per capita increases by 1%. It measures the additional risk that the action imposes on the community. On average, it should be around 1. As we see from Table 3.3, the risk premium as measured by the difference between the rate of return on bonds and the rate of return on equity is between 3% and 6%. A more normative approach described by the consumption-based capital asset pricing model (Cochrane, 2001) would lead to a much smaller risk premium equalling $\pi_{gt} = \eta\sigma_t^2$ if calibrated on the volatility of growth in western economies.[16] However, Barro (2006, 2009) and Martin (2013) recently showed that the introduction of rare catastrophic events – similar to those observed in some developing countries during the last century – can justify using a low safe discount rate of around 1% and a large aggregate risk premium of around 4% at the same time. The true discount rate to be used in the context of climate change will then rely heavily on the climate beta. So far, almost no research has been conducted on the value of the climate beta, that is, the statistical relationship between the level of climate damage and the level of consumption per capita in the future. The exception is Sandsmark and Vennemo (2006), who suggest that it is almost zero. But existing Integrated Assessment Models (IAMs) show that more climate damage is incurred in scenarios with higher economic growth, suggesting that combating climate change does not provide a hedge against the global risk borne by future generations. Nordhaus (2011b) assumes that the actual damages borne by future generations are increasing, so that the climate beta is positive, and the discount rate for climate change should be larger than just applying the extended Ramsey rule.

Several authors (Malinvaud, 1953; Guesnerie, 2004; Weikard and Zhu, 2005; Hoel and Sterner, 2007; Sterner and Persson, 2008; Gollier, 2010; Traeger, 2011; Guéant et al., 2012) emphasize the need to take into account the evolution of relative prices in CBAs involving the distant future. In a growing economy, non-reproducible goods like environmental assets will become relatively scarcer in the future, thereby implying an increasing social value.

[16] With a volatility in the growth rate of consumption per capita around σ_t =4% (see Table 3.3), and a degree of inequality aversion of ,$\eta = 2$, we obtain a risk premium of only $\pi_{gt} = 0.32\%$.

3.6.3 Co-benefits and adverse side effects

This Section defines the concept of co-benefits and provides a general framework for analysis in other chapters (a negative co-benefit is labelled an 'adverse side effect'). A good example of a co-benefit in the literature is the reduction of local pollutants resulting from a carbon policy that reduces the use of fossil fuels and fossil-fuel-related local pollutants (see sections 5.7 and 6.6.2.1). It is also important to distinguish between co-benefits and the societal welfare consequences of generated co-benefits. To use the same example, if local pollutants are already heavily regulated, then the net welfare benefits of further reductions in local pollutants may be small or even negative.

3.6.3.1 A general framework for evaluation of co-benefits and adverse side effects

As a simple example, suppose social welfare V is a function of different goods or objectives z_i ($i = 1, \ldots, m$), and that each of those objectives might be influenced by some policy instrument, p_1.[17] The policy may have an impact on several objectives at the same time. Now consider a marginal change dp_1 in the policy. The welfare effect is given by:

Equation 3.6.6. $$\boldsymbol{dV} = \sum_{i=1}^{m} \frac{\partial V}{\partial z_i} \frac{\partial z_i}{\partial p_1} dp_1$$

For example, suppose $dp_1 > 0$ is additional GHG abatement (tightening the cap on CO_2 emissions). Then the 'direct' benefits of that climate policy might include effects on climate objectives, such as mean global temperature (z_1), sea level rise (z_2), lost agricultural productivity (z_3), lost biodiversity (z_4), and health effects of global warming (z_5). The 'co-benefits' of that climate policy might include changes in a set of objectives such as SO_2 emissions (z_6), energy security (z_7), labour supply and employment (z_8), the distribution of income (z_9), the degree of urban sprawl (z_{10}), and the sustainability of the growth of developing countries (z_{11}). See Table 15.1 for an overview of objectives discussed in the sector chapters in the context of co-benefits and adverse side-effects. The few studies that attempt a full evaluation of the global welfare effects of mitigation co-benefits focus only on a few objectives because of methodological challenges (as assessed in Section 6.6). For discussion of income distribution objectives, see the 'social welfare functions' in Subsection 3.4.6 .

Because this problem inherently involves multiple objectives, it can be analysed using Multi-Criteria Analysis (MCA) that "requires policymakers to state explicit reasons for choosing policies, with reference to the multiple objectives that each policy seeks to achieve" (Dubash et al., 2013, p. 47). See also Subsection 3.7.2.1, Section 6.6 and (McCollum et al., 2012).

Even external effects on public health could turn out to be either direct benefits of climate policy or co-benefits. The social cost of carbon includes the increased future incidence of heat stroke, heart attacks, malaria and other warm climate diseases. Any reduction in such health-related costs of climate change is therefore a direct benefit of climate policy. The definition of a co-benefit is limited to the effect of reductions in health effects caused by non-climate impacts of mitigation efforts.

Use of the terminology should be clear and consistent. CBAs need to include *all* gains and losses from the climate policy being analysed – as shown in Equation 3.6.6 – the sum of welfare effects from direct benefits net of costs, plus the welfare effects of co-benefits and adverse side-effects.

Here, the co-benefit is defined as the effect on a non-climate objective $(\partial z_i/\partial p_1)$, leaving aside social welfare (not multiplied by $\partial V/\partial z_i$). In contrast, the 'value' of the co-benefit is the effect on social welfare $(\partial V/\partial z_i)$, which could be evaluated by economists using valuation methods discussed elsewhere in this Chapter.[18] It may require use of a 'second-best' analysis that accounts for multiple

[17] This *V* is a loose interpretation of a social welfare function, such as defined in Equation 3.6.2, insofar as welfare is not usually represented a function of policy objectives or aggregate quantities of goods.

[18] We distinguish here between the welfare effect of the co-benefit $(\partial V/\partial z_i)$ and the welfare effect of the policy operating through a particular co-benefit $(\frac{\partial V}{\partial z_i}\frac{\partial z_i}{\partial p_1} dp_1)$.

market distortions (Lipsey and Lancaster, 1956). This is not a minor issue. In particular, $\partial V/\partial z_i$ may be positive or negative.

The full evaluation of dV in the equation above involves four steps: first, identify the various multiple objectives z_i $(i = 1, \ldots, m)$ (see, e.g., Table 4.8.1 for a particular climate policy such as a CO_2 emissions cap); second, identify all significant effects on all those objectives (direct effects and co-effects $\frac{\partial z_i}{\partial p_1}$, for $i = 1, \ldots, m$) (see Chapters 7–12); third, evaluate each effect on social welfare (multiply each $\partial z_i/\partial p_1$ by $\partial V/\partial z_i$); and fourth, aggregate them as in Equation 3.6.6. Of course, computing social welfare also has normative dimensions (see Subsection 3.4.6).

3.6.3.2 The valuation of co-benefits and adverse side effects

The list of goods or objectives z_i $(i = 1, \ldots, m)$ could include any commodity, but some formulations allow the omission of goods sold in markets with no market failure or distortion, where the social marginal benefit (all to the consumer) is equal to the social marginal cost (all on the producer). With no distortion in a market for good i, a small change in quantity has no net effect on welfare ($\partial V/\partial z_i = 0$). The effect on welfare is *not* zero, however, if climate policy affects the quantity of a good sold in a market with a 'market failure', such as non-competitive market power, an externality, or any pre-existing tax. In general, either monopoly power or a tax would raise the price paid by consumers relative to the marginal cost faced by producers. In such cases, any increase in the commodity would have a social marginal benefit higher than social marginal cost (a net gain in welfare).

We now describe a set of studies that have evaluated some co-benefits and adverse side effects (many more studies are reviewed in sections 5.7, 7.9, 8.7, 9.7, 10.8, 11.7, 12.8 and synthesized in section 6.6). First, oligopolies may exert market power and raise prices above marginal cost in large industries such as natural resource extraction, iron and steel, or cement. And climate policy may affect that market power. Ryan (2012) finds that a prominent environmental policy in the United States actually increased the market power of incumbent cement manufactures, because it decreased competition from potential entrants that faced higher sunk costs. That is, it created barriers to entry. That effect led to a significant loss in consumer surplus that was not incorporated in the policy's initial benefit-cost analysis.

Second, Ren et al. (2011) point out that a climate policy to reduce CO_2 emissions may increase the use of biofuels, but that "corn-based ethanol production discharges nitrogen into the water environment … [which] … can cause respiratory problems in infants and exacerbate algae growth and hypoxia in water bodies" (p. 498). In other words, a change in climate policy (dp_1) affects the use of nitrogen fertilizer and its runoff ($\partial z_i/\partial p_1$). The effect is an 'adverse side effect.' If nitrogen runoff regulation is less than optimal, the effect on social welfare is negative ($\partial V/\partial z_i$<0).

Third, arguably the most studied co-benefits of climate policy are the effects on local air pollutant emissions, air quality, and health effects of ground-level ozone (see section 6.6 for a synthesis of findings from scenario literature and sector-specific measures). Burtraw et al. (2003) conclude that a \$25 per tonne carbon tax in the United States would reduce NO_X emissions and thereby provide health improvements. Further, the researchers valued these health co-benefits at \$8 per tonne of carbon reduction in the year 2010 (in 1997 dollars). More recently, Groosman et al. (2011) model a specific U.S. climate policy proposal (Warner-Lieberman (S.2191)). They calculate effects on health from changes in local flow pollutants (a co-benefit). These health co-benefits mainly come from reductions in particulates and ozone, attributable to reductions in use of coal-fired power plants (Burtraw et al., 2003; Groosman et al., 2011).[19] The authors also value that co-benefit at \$103 billion

[19] Both of the cited studies estimate the dollar value of health improvements, but these are "'gross'" benefits that may or may not correctly account for the offsetting effects of existing controls on these local pollution emissions, which is necessary to determine the net welfare effects.

to \$1.2 trillion for the years 2010–2030 (in present value 2006 dollars). That total amount corresponds to \$1 to \$77 per tonne of CO_2 (depending on model assumptions and year; see section 5.7 for a review of a broader set of studies with higher values particularly for developing countries).

Researchers have calculated climate policy co-benefits in many other countries; for instance, Sweden (Riekkola et al., 2011), China (Aunan et al., 2004), and Chile (Dessus and O'Connor, 2003).

A complete analysis of climate policy would measure all such direct or side effects ($\partial z_i/\partial p_1$) while recognizing that other markets may be functioning properly or be partially regulated (for optimal regulation, $\partial V/\partial z_i$ = 0). If the externality from SO_2 is already partly corrected by a tax or permit price that is less than the marginal environmental damage (MED) of SO_2, for example, then the welfare gain from a small reduction in SO_2 may be less than its MED. Or, if the price per tonne of SO_2 is equal to its MED, and climate policy causes a small reduction in SO_2, then the social value of that co-benefit is zero.[20] Similarly, if the labour market is functioning properly with no involuntary unemployment, then climate policy may have direct costs from use of that labour but no welfare gain from changes in employment. In other words, in measuring the welfare effects of co-benefits, it is not generally appropriate simply to use the gross marginal value associated with a co-benefit.

In the context of externalities and taxes, this point can be formalized by the following extension of Fullerton and Metcalf (2001):

Equation 3.6.7. $$dV = {}_{i=1}^{m}(t_i - \mu_i)\frac{\partial z_i}{\partial p_1}dp_1$$

On the right side of the equation, μ_i is the MED from the i^{th} commodity; and t_i is its tax rate (or permit price, or the effect of a mandate that makes an input such as emissions more costly). The effect of each good on welfare ($\partial V/\partial z_i$ in Equation 3.6.6 above) is reduced in this model to just $(t_i - \mu_i)$. The intuition is simple: t_i is the buyer's social marginal benefit minus the seller's cost; the externality μ_i is the social marginal cost minus the seller's cost. Therefore, $(t_i - \mu_i)$ is the social marginal benefit minus social marginal cost. It is the net effect on welfare from a change in that commodity. If every externality μ_i is corrected by a tax rate or price exactly equal to μ_i , then the outcome is 'first best'. In that case, dV in Equation 3.6.7 is equal to zero, which means welfare cannot be improved by any change in any policy. If any t_i is not equal to μ_i, however, then the outcome is not optimal, and a 'second best' policy might improve welfare if it has any direct or indirect effect on the amount of that good.

Although the model underlying Equation 3.6.7 is static and climate change is inherently dynamic, the concepts represented in the static model can be used to understand the application to climate. Climate policy reduces carbon emissions, but Equation 3.6.7 shows that this 'direct' effect does not add to social welfare unless the damage per tonne of carbon (μ_C) exceeds the tax on carbon (t_C). The social cost of carbon is discussed in Subsection 3.9.4 . To see a co-benefit in this equation, suppose z_S is the quantity of SO_2 emissions, t_S is the tax per tonne, and μ_S is the MED of additional SO_2. If the tax on SO_2 is too small to correct for the externality ($t_S - \mu_S < 0$), then the market provides 'too much' of it, and any policy such as a carbon tax that reduces the amount of SO_2 ($\partial z_S/\partial p_1 < 0$) would increase economic welfare. The equation sums over all such effects in all markets for all other inputs, outputs and pollutants.

If those local pollution externalities are already completely corrected by a tax or other policy ($t_S = \mu_S$), however, then a reduction in SO_2 adds nothing to welfare. The existing policy raises the firm's cost of SO_2 emissions by exactly the MED. That firm's consumers reap the full social marginal benefit per tonne of SO_2 through consumption of the output, but those consumers also pay the full social marginal cost per tonne of SO_2. In that case, one additional tonne of SO_2 has social costs

[20] This "marginal" analysis contemplates a small change in either CO_2 or SO_2. If either of those changes are large, however, then the analysis is somewhat different.

exactly equal to social benefits, so any small increase or decrease in SO_2 emissions caused by climate policy provides no net social gain. In fact, if $t_S > \mu_S$, then those emissions are already over-corrected, and any decrease in SO_2 would reduce welfare.

3.6.3.3 The double dividend hypothesis

Another good example of a co-benefit arises from the interaction between carbon policies and other policies (Parry, 1997; Parry and Williams, 1999). Though enacted to reduce GHG emissions, a climate policy may also raise product prices and thus interact with other taxes that also raise product prices. Since the excess burden of taxation rises more than proportionately with the size of the overall effective marginal tax rate, the carbon policy's addition to excess burden may be much larger if it is added into a system with high taxes on output or inputs.

This logic has given rise to the 'double dividend hypothesis' that an emissions tax can both improve the environment and provide revenue to reduce other distorting taxes and thus improve efficiency of the tax system (e.g., Oates and Schwab, 1988; Pearce, 1991; Parry, 1995; Stern, 2009).[21] Parry (1997) and Goulder et al. (1997) conclude that the implementation of a carbon tax or emissions trading can increase the deadweight loss of pre-existing labour tax distortions (the 'tax interaction effect'), but revenue can be used to offset distortionary taxes (the 'revenue recycling effect'). Parry and Williams (1999) investigate the impacts of existing tax distortions in the labour market for eight climate policy instruments (including energy taxes and performance standards) for the United States in 1995. They conclude that pre-existing tax distortions raise the costs of all abatement policies, so the co-benefits of carbon taxes or emissions trading depend on whether generated revenues can be directed to reduce other distortionary taxes. A lesson is that forgoing revenue raising opportunities from a GHG regulation can significantly increase inefficiencies. The European Union is auctioning an increasing share of permits with revenue going to Member States (see 14.4.2). Australia is using a large share of carbon pricing revenue to reduce income tax (Jotzo, 2012).

To put this discussion into the context of co-benefits, note that Fullerton and Metcalf (2001) use their version of Equation 3.6.7 to consider labour (z_L), taxed at a pre-existing rate t_L (with marginal external damages of zero, so $\mu_L = 0$). Suppose the only other distortion is from carbon emissions (z_C), with MED of μ_C. Thus the economy has 'too little' labour supply, and 'too much' pollution. The combination 'policy change' is a small carbon tax with revenue used to cut the tax rate t_L. Other taxes and damages are zero ($t_i = \mu_i = 0$) for all goods other than z_L and z_C. Thus, Equation 3.6.7 above simplifies further, to show that the two key outcomes are just the net effect on pollution (dz_C) and the net effect on labour (dz_L):

Equation 3.6.8. $$dV = t_L dz_L + (t_C - \mu_C) dz_C$$

Therefore, an increase in the carbon tax that reduces emissions ($dz_C < 0$) has a direct benefit of increased economic welfare through the second term, but only to the extent that emissions damages exceed the tax rate ($\mu_C > t_C$). If the labour tax cut increases labour supply, then the first term also increases welfare (a double dividend). But the carbon tax also raises the cost of production and the equilibrium output price, which itself *reduces* the *real* net wage (the tax interaction effect). If that effect dominates the reduction in the labour tax rate (from the revenue recycling effect), then labour supply may fall ($dz_L < 0$). In that case, the first term has a negative effect on wellbeing. In other words, the double-dividend is possible under some circumstances and not others. If the revenue is *not* used to cut the labour tax rate, then the real net wage does fall, and the labour supply may fall.

[21] The literature contains two versions of the double dividend hypothesis. A '"strong'" version says that efficiency gains from diminishing distortionary taxes can more than compensate the costs of pollution taxes. Another '"weak'" version says that those gains compensate only part of the costs of pollution taxes (Goulder, 1995).

3.7 Assessing methods of policy choice

Specific climate policies are discussed in Section 3.8; in this Section, we discuss methods for evaluating the relative merits of different policies. See also Alkin (2004), Pawson and Tilley (1997), Bardach (2005), Majchrzak (1984), Scriven (1991) Rossi et al. (2005) and Chen (1990). The design and choice of a specific climate policy instrument (or mix of instruments) depends on many economic, social, cultural, ethical, institutional and political contexts. Different methods for ex-ante and ex-post analysis are available and different types of analytical approaches may be used in tandem to provide perspectives to policymakers.

3.7.1 Policy objectives and evaluation criteria

In addition to reducing GHG emissions, climate policy may have other objectives. Following AR4 (Gupta et al., 2007), these objectives are organized below in four broad categories: economic, distributional/fairness, environmental, and institutional/political feasibility.22 The relative importance of these policy objectives differs among countries, especially between developed and developing countries.

In this Subsection we discuss elements of these four categories and expand on recent policy evaluation studies (e.g., Opschoor and Turner, 1994; Ostrom, 1999; Faure and Skogh, 2003; Sterner, 2003; Mickwitz, 2003; Blok, 2007), leaving details of applications and evidence to Chapters 8–11 and 13–15.

The basic economic framework for policy analysis is depicted in Figure 3.3 (adapted from Fullerton (2011)). This diagram illustrates both the impacts of policies and the criteria for evaluating them in the context of the production of a polluting good (i.e., emissions associated with producing a good). The focus is stylized, but we note that many 'non-economic' values can still be incorporated, to the extent that values can be placed on other considerations, such as effects on nature, culture, biodiversity and 'dignity' (see Subsections 3.4.1 and 3.4.2).

As shown in Figure 3.3, the quantity of GHG emissions from producing a good, such as electricity, is shown on the horizontal axis, and the price or cost per unit of that good is shown on the vertical axis. The demand for the emissions is derived from the demand for electricity, as shown by the curve called Private Marginal Benefit (PMB). The private market supply curve is the Private Marginal Cost (PMC) of production, and so the unfettered equilibrium quantity would be Q^0 at equilibrium price P^0. This polluting activity generates external costs, however, and so each unit of output has a Social Marginal Cost (SMC) measured by the vertical sum of PMC plus Marginal External Cost (MEC). With no externalities on the demand side, PMB=SMB.

[22] Political factors have often been more important than economic ones in explaining instrument choice (Hepburn, 2006). Redistribution to low-income households is an important feature in Australia's emissions pricing policy (Jotzo and Hatfield-Dodds, 2011).

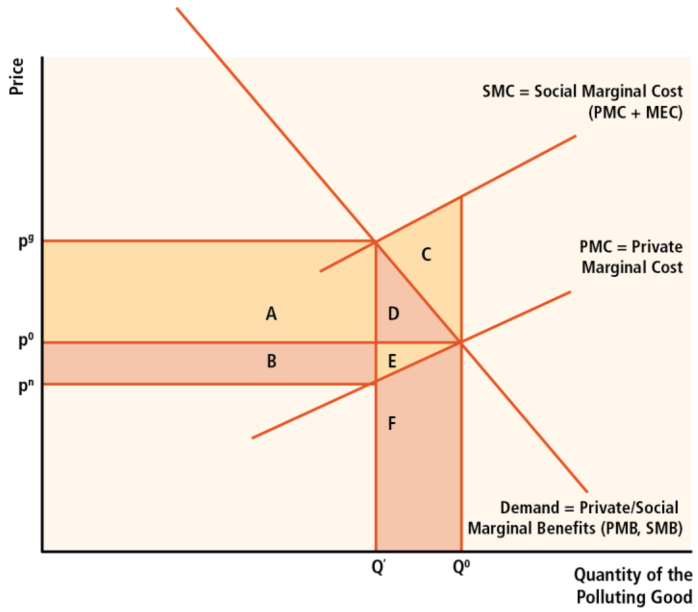

Figure 3.3. A partial equilibrium model of the costs and benefits of a market output, assuming perfect competition, perfect information, perfect mobility, full employment and many identical consumers (so all individuals equally benefit from production and they equally bear the external cost of pollution).

Under the stated simplifying assumptions, the social optimum is where SMC=PMB, at Q'. The first point here, then, is that the optimal quantity can be achieved by several different policies under these simple conditions. A simple regulatory quota could restrict output from Q0 to Q', or a fixed number of tradeable permits could restrict pollution to the quantity Q'. In that case, Pn is the equilibrium price net of permit cost (the price received by the firm), while Pg is the price gross of permit cost (paid by the consumer). The permit price is the difference, Pg - Pn. Alternatively, a tax of (Pg - Pn) per unit of pollution would raise the firm's cost to SMC and result in equilibrium quantity Q'.

This diagram will be used below to show how the equivalence of these instruments breaks down under more general circumstances, as well as gains and losses to various groups. In other words, we use this diagram to discuss economic as well as distributional, other environmental and cultural objectives, and institutional/political feasibility.

3.7.1.1 Economic objectives

Economic efficiency. Consider an economy's allocation of resources (goods, services, inputs and productive activities). An allocation is efficient if it is not possible to reallocate resources so as to make at least one person better off without making someone else worse off. This is also known as the Pareto criterion for efficiency (discussed in Subsection 3.6.1) (see e.g., Sterner, 2003; Harrington et al., 2004; Tietenberg, 2006). In Figure 3.3, any reduction in output from Q^0 improves efficiency because it saves costs (height of SMC) that exceed the benefits of that output (height of PMB).[23] This reduction can be achieved by a tax levied on the externality (a carbon tax), or by tradeable emission permits. Further reductions in output generate further net gains, by the extent to which SMC exceeds SMB, until output is reduced to Q' (where SMC=SMB). Hence, the gain in economic efficiency is area C. Perfect efficiency is difficult to achieve, for practical reasons, but initial steps from Q^0 achieve a larger gain (SMC>SMB) than the last step to Q' (because SMC≈SMB near the left point of triangle C).

[23] Other approaches are discussed in Section 3.11 .

An aspect of economic efficiency over time is the extent to which a carbon policy encourages the right amount of investment in research, innovation and technological change, in order to reduce GHG emissions more cheaply (Jung et al., 1996; Mundaca and Neij, 2009). See Section 3.11 .

Cost-effectiveness. Pollution per unit of output in Figure 3.3 is fixed, but actual technologies provide different ways of reducing pollution per unit of output. A policy is cost-effective if it reduces pollution (given a climate target) at lowest cost. An important condition of cost-effectiveness is that marginal compliance costs should be equal among parties (ignoring other distortions such as regulations) (Babiker et al., 2004)).

Transaction costs. In addition to the price paid or received, market actors face other costs in initiating and completing transactions. These costs alter the performance and relative effectiveness of different policies and need to be considered in their design, implementation and assessment (Mundaca et al., 2013; see also Matthews, 1986, p. 906).

3.7.1.2 Distributional objectives

Six distributional effects. A policy may generate gains to some and losses to others. The fairness or overall welfare consequences of these distributional effects is important to many people and can be evaluated using a SWF, as discussed in Subsection 3.4.6 . They fall into six categories (Fullerton, 2011). In Figure 3.3, any policy instrument might reduce the quantity of polluting output, such as from Q^0 to Q', which reduces emissions, raises the equilibrium price paid by consumers (from P^0 to P^g), and reduces the price received by firms (from P^0 to P^n). The six effects are illustrated in Box 3.6. The framework can be applied to any environmental problem and any policy to correct it.

Box 3.6 Six distributional effects of climate policy, illustrated for a permit obligation or emissions tax on coal-fired electricity, under the assumption of perfectly competitive electricity markets.

First, the policy raises the cost of generating electricity and if cost increases are passed through to consumers, for example through competitive markets or changes in regulated prices, the consumer's price (from P^0 to P^g), so it reduces consumer surplus. In Figure 3.3, the loss to consumers is the sum of areas A+D. Losses are greater for those who spend more on electricity.

Second, it reduces the net price received by the firm (from P^0 to P^n), so it reduces producer surplus by the sum of areas B+E. The effect is reduced payments to factors of production, such as labour and capital. Losses are greater for those who receive more income from the displaced factor.

Third, pollution and output are restricted, so the policy generates 'scarcity rents' such as the value of a restricted number of permits (areas A+B). If the permits are given to firms, these rents accrue to shareholders. The government could partly or fully capture the rents by selling the permits or by a tax per unit of emissions (Fullerton and Metcalf, 2001).

Fourth, because the policy restricts GHG emissions, it confers benefits on those who would otherwise suffer from climate change. The value of those benefits is areas C+D+E.

Fifth, the electricity sector uses less labour, capital and other resources. It no longer pays them (areas E+F). With perfect mobility, these factors are immediately redeployed elsewhere, with no loss. In practice however, social costs may be substantial, including transaction costs of shifting to other industries or regions, transitional or permanent unemployment, and social and psychological displacement.

Sixth, any gain or loss described above can be capitalized into asset prices, with substantial immediate effects for current owners. For example, the value of a corporation that owns coal-fired generation assets may fall, in line with the expected present value of the policy change, while the value of corporations that own low-emissions generation technologies may rise.

The connection between these distributional effects and 'economic efficiency' is revealed by adding up all the gains and losses just described: the consumer surplus loss is A+D; producer surplus loss is B+E; the gain in scarcity rents is A+B; and the environmental gain is C+D+E, assuming the gainers and losers receive equal weights. The net sum of the gains and losses is area C, described above as the net gain in economic efficiency.

In many cases, a distributional implication of imposing efficient externality pricing (e.g., area A+B) is much larger than the efficiency gains (area C). This illustrates the importance of distributional considerations in discussions on emissions-reducing policies, and it indicates why distributional considerations often loom large in debates about climate policy.

With reference to Box 3.6, the first effect of a carbon policy on consumers is generally regressive (though most analyses are for developed countries), because the higher price of electricity imposes a heavier burden on lower income groups who spend more of their income on electricity (Metcalf, 1999; Grainger and Kolstad, 2010). However, fuel taxes tend to be progressive in developing countries (Sterner, 2011). The sign of the second effect, on factors of production, is generally ambiguous. The third effect is regressive if permits are given to firms, because then profits accrue to shareholders who tend to be in high-income brackets (Parry, 2004). But if government captures the scarcity rents by selling permits or through a carbon tax, the funds can be used to offset burdens on low-income consumers and make the overall effect progressive instead of regressive. Other effects are quite difficult to measure.

Much of the literature on 'environmental justice' discusses the potential effects of a pollution policy on neighbourhoods with residents from different income or ethnic groups (Sieg et al., 2004). Climate policies affect both GHG emissions and other local pollutants such as SO_2 or NO_X, whose concentrations vary widely. Furthermore, the cost of GHG mitigation may not be shared equally among all income or ethnic groups. And even 'global' climate change can have different temperature impacts on different areas, or other differential effects (e.g., on coastal areas via rise in sea level).

The distributional impacts of policies include aspects such as fairness/ equity (Gupta et al., 2007). A perceived unfair distribution of costs and benefits could prove politically challenging (see below), since efficiency may be gained at the expense of equity objectives.

3.7.1.3 Environmental objectives

Environmental effectiveness. A policy is environmentally effective if it achieves its expected environmental target (e.g., GHG emission reduction). The simple policies mentioned above might be equally effective in reducing pollution (from Q^0 to Q' in Figure 3.3), but actual policies differ in terms of ambition levels, enforcement and compliance.

Co-benefits. Climate policy may reduce both GHG emissions and local pollutants, such as SO_2 emissions that cause acid rain, or NO_X emissions that contribute to ground level ozone. As described in Subsection 3.6.3, reductions in other pollutants may not yield any net gain to society if they are already optimally regulated (where their marginal abatement costs and their marginal damages are equal). If pollutants are inefficiently regulated, however, climate regulations can yield positive or negative net social gains by reducing them.

Climate policy is also likely to affect other national objectives, such as energy security. For countries that want to reduce their dependence on imported fossil fuels, climate policy can bolster energy efficiency and the domestic renewable energy supply, while cutting GHG emissions. See Subsection 3.6.3 on co-benefits.

Carbon leakage. The effectiveness of a national policy to reduce emissions can be undermined if it results in increased emissions in other countries, for example, because of trading advantages in countries with more relaxed policies (see Subsection 3.9.5). Another type of leakage occurs within emission trading systems. Unilateral emission reductions by one party will release emission permits and be outweighed by new emissions within the trading regime.

3.7.1.4 Institutional and political feasibility

Administrative burden. This depends on how a policy is implemented, monitored, and enforced (Nordhaus and Danish, 2003). The size of the burden reflects, inter alia, the institutional framework, human and financial costs and policy objectives (Nordhaus and Danish, 2003; Mundaca et al., 2010). Administrative costs in public policy are often overlooked (Tietenberg, 2006)

Political feasibility is the likelihood of a policy gaining acceptance and being adopted and implemented (Gupta et al., 2007, p. 785). It covers the obstacles faced and key design features that can generate or reduce resistance among political parties (Nordhaus and Danish, 2003). Political feasibility may also depend on environmental effectiveness and whether regulatory and other costs are equitably distributed across society (Rist, 1998). The ability of governments to implement political decisions may be hampered by interest groups; policies will be more feasible if the benefits can be used to buy the support of a winning coalition (Compston, 2010). *Ex ante*, these criteria can be used in assessing and improving policies. *Ex post*, they can be used to verify results, withdraw inefficient policies and correct policy performance. For specific applications, see Chapters 7-15.

3.7.2 Analytical methods for decision support

Previous IPCC Assessment Reports have addressed analytical methods to support decision-making, including both numerical and case-based methods. Bruce et al. (1996, chap. 2 and 10) focus heavily on quantitative methods and IAMs. Metz et al. (2001) provide a wider review of approaches, including emerging participatory forms of decision-making. Metz et al. (2007) briefly elaborate on quantitative methods and list sociological analytical frameworks. In this Subsection, we summarize the core information on methodologies separated into quantitative- and qualitative-oriented approaches.

3.7.2.1 Quantitative-oriented approaches

In decision-making, quantitative methods can be used to organize and manage numerical information, provide structured analytical frameworks, and generate alternative scenarios – with different levels of uncertainty (Majchrzak, 1984). An approach that attempts to estimate and aggregate monetized values of all costs and benefits that could result from a policy is CBA. It may require estimating non-market values, and choosing a discount rate to express all costs and benefits in present value. When benefits are difficult to estimate in monetary terms, a Cost-Effectiveness Analysis (CEA) may be preferable. A CEA can be used to compare the costs of different policy options (Tietenberg, 2006) for achieving a well-defined goal. It can also estimate and identify the lowest possible compliance costs, thereby generating a ranking of policy alternatives (Levin and McEwan, 2001). Both CEA and CBA are similarly limited in their ability to generate data, measure and value future intangible costs.

Various types of model can provide information for CBA, including energy-economy-environment models that study energy systems and transitions towards more sustainable technology. A common classification of model methodologies includes ‘bottom-up’ and ‘top-down’ approaches. ‘Hybrids’ of the two can compensate for some known limitations and inherent uncertainties (Rivers and Jaccard, 2006):[24]

[24] The literature acknowledges that it is difficult to make a clear classification among modelling approaches, as variations among categories and also alternative simulation methodologies do exist (e.g. macroeconometric Keynesian models, agent-based approaches) (Hourcade et al., 2006; Mundaca et al., 2010; Scrieciu et al., 2013).

- Given exogenously defined macroeconomic and demographic scenarios, 'bottom-up' models can provide detailed representations of supply- and demand-side technology paths that combine both cost and performance data. Conventional bottom-up models may lack a realistic representation of behaviour (e.g. heterogeneity) and may overlook critical market imperfections, such as transaction costs and information asymmetries (e.g.,Craig et al., 2002; DeCanio, 2003; Greening and Bernow, 2004).
- By contrast, 'top-down' models, such as computable general equilibrium (CGE), represent technology and behaviour using an aggregate production function for each sector to analyse effects of policies on economic growth, trade, employment and public revenues (see, e.g., DeCanio, 2003). They are often calibrated on real data from the economy. However, such models may not represent all markets, all separate policies, all technological flexibility, and all market imperfections (Laitner et al., 2003). Parameters are estimated from historical data, so forecasts may not predict a future that is fundamentally different from past experience (i.e., path dependency) (Scheraga, 1994; Hourcade et al., 2006). For potential technology change, many models use sub-models of specific supply or end-use devices based on engineering data (Jacoby et al., 2006; Richels and Blanford, 2008; Lüken et al., 2011; Karplus et al., 2013).

With CBA, it is difficult to reduce all social objectives to a single metric. One approach to dealing with the multiple evaluation criteria is Multi-Criteria Analysis, or MCA (Keeney and Raiffa, 1993; Greening and Bernow, 2004). Some argue that analysing environmental and energy policies is a multi-criteria problem, involving numerous decision makers with diverse objectives and levels of understanding of the science and complexity of analytical tools (Sterner, 2003; Greening and Bernow, 2004). The advantage of MCA is that the analyst does not have to determine how outcomes are traded off by the policy maker. For instance, costs can be separated from ecosystem losses. But even with MCA, one must ultimately determine the appropriate trade-off rates among the different objectives. Nevertheless, it can be a useful way of analysing problems where being restricted to one metric is problematic, either politically or practically. CGE models can specify consumer and producer behaviour and 'simulate' effects of climate policy on various outcomes, including real gains and losses to different groups (e.g., households that differ in income, region or demographic characteristics). With behavioural reactions, direct burdens are shifted from one taxpayer to another through changes in prices paid for various outputs and received for various inputs. A significant challenge is the definition of a 'welfare baseline' (i.e., identifying each welfare level without a specific policy).

Integrated Assessment Models (IAMs) or simply Integrated Models (IAs) combine some or all of the relevant components necessary to evaluate the consequences of mitigation policies on economic activity, the global climate, the impacts of associated climate change and the relevance of that change to people, societies and economies. Some models may only be able to represent how the economy responds to mitigation policy and no more; some models may include a physical model of the climate and be able to translate changes in emissions into changes in global temperature; some models may also include a representation of the impacts of climate change; and some models may translate those impacts into damage to society and economies. Models can be highly aggregate (often termed "top-down") or detailed process analysis models ("bottom-up"), or a combination of both (see also Chapter 6). Some IAMs relate climate change variables with other physical and biological variables like crop yield, food prices, premature death, flooding or drought events, or land use change (Reilly et al., 2013). Computational limits may preclude the scales required for some climate processes (Donner and Large, 2008),[25] but recent attempts are directed towards integrating human activities with full Earth System models (Jones et al., 2013). All of the models used in WGIII

[25] Stanton et al. (2009) also place climate change models into categories (welfare maximization, general equilibrium, partial equilibrium, cost minimization and simulation models).

(primarily Chapter 6) focus on how mitigation policies translate into emissions; none of those models have a representation of climate damages. IAMs have been criticized in recent years (e.g.,Ackerman et al., 2009; Pindyck, 2013). Much of the most recent criticism is directed at models that include a representation of climate damage; none of the models used in Chapter 6 fall into this category. Refer to Chapter 6 for more detail in this regard.

Other quantitative-oriented approaches to support policy evaluation include tolerable windows (Bruckner et al., 1999), safe-landing/guard rail (Alcamo and Kreileman, 1996), and portfolio theory (Howarth, 1996). Outside economics, those who study decision sciences emphasize the importance of facing difficult value-based trade-offs across objectives, and the relevance of various techniques to help stakeholders address trade-offs (see, e.g., Keeney and Raiffa, 1993).

3.7.2.2 Qualitative approaches

Various qualitative policy evaluation approaches focus on the social, ethical and cultural dimensions of climate policy. They sometimes complement quantitative approaches by considering contextual differences, multiple decision makers, bounded rationality, information asymmetries and political and negotiation processes (Toth et al., 2001; Halsnæs et al., 2007). Sociological analytical approaches examine human behaviour and climate change (Blumer, 1956), including beliefs, attitudes, values, norms and social structures (Rosa and Dietz, 1998). Focus groups can capture the fact that “people often need to listen to others’ opinions and understandings to form their own” (Marshall and Rossman, 2006, p. 114). Participatory approaches focus on process, involving the active participation of various actors in a given decision-making process (van den Hove, 2000). Participatory approaches in support of decision-making include appreciation-influence-control, goal oriented project planning, participatory rural appraisal, and beneficiary assessment. MCA can also take a purely qualitative form. For the pros and cons of participatory approaches, see Toth et al. (2001, p. 652). Other qualitative-oriented approaches include systematic client consultation, social assessment and team up (Toth et al., 2001; Halsnæs et al., 2007).

3.8 Policy instruments and regulations

A broad range of policy instruments for climate change mitigation is available to policymakers. These include economic incentives, such as taxes, tradeable allowances, subsidies; direct regulatory approaches, such as technology or performance standards; information programs; government provision, of technologies or products; and voluntary actions.

Chapter 13 of AR4 provided a typology and definition of mitigation policy instruments. Here we present an update on the basis of new research on the design, applicability, interaction and political economy of policy instruments, as well as on applicability of policy instruments in developed and developing countries. For details about applications and empirical assessments of mitigation policy instruments, see Chapters 7–12 (sectoral level), Chapter 13 (international cooperation), Chapter 14 (regional cooperation) and Chapter 15 (national and sub-national policies).

3.8.1 Economic incentives

Economic (or market) instruments include incentives that alter the conditions or behaviour of target participants and lead to a reduction in aggregate emissions. In economic policy instruments a distinction is made between ‘price’ and ‘quantity’. A tradeable allowance or permit system represents a quantity policy whereby the total quantity of pollution (a cap) is defined, and trading in emission rights under that cap is allowed. A price instrument requires polluters to pay a fixed price per unit of emissions (tax or charge), regardless of the quantity of emissions.

3.8.1.1 Emissions taxes and permit trading

Both the approaches described above create a price signal as an incentive to reducing emissions, which can extend throughout the economy. Economic instruments will tend to be more cost-effective than regulatory interventions and may be less susceptible to rent seeking by interest groups. The empirical evidence is that economic instruments have, on the whole, performed better than regulatory instruments, but that in many cases improvements could have been made through better policy design (Hahn, 1989; Anthoff and Hahn, 2010).

Box 3.7 Equivalence of emissions taxes and permit trading schemes

Price-based and quantity-based instruments are equivalent under certainty, but differ in the extent of mitigation and costs if emissions and abatement costs are uncertain to the regulator (Weitzman, 1974) . Hybrid instruments, where a quantity constraint can be overridden if the price is higher or lower than a threshold, have been shown to be more efficient under uncertainty (Roberts and Spence, 1976; McKibbin and Wilcoxen, 2002; Pizer, 2002). Variants of hybrid approaches featuring price ceilings and price floors have been implemented in recent emissions trading schemes (Chapters 14 and 15). The possibility of periodic adjustments to tax rates and caps and their implementation under permit schemes further breaks down the distinction between price-based and quantity-based market-based instruments.

Equivalence also exists for fiscal effects and the costs imposed on emitters. Until recently, most of the literature has assumed that emissions taxes and permit trading differ in the revenue they yield for governments and the costs imposed on emitters, assuming that emissions tax revenue fully accrues to governments while under emissions trading schemes permits are given freely to emitters. This was also the case in early policy practice (Chapters 14 and 15). It has been widely assumed that permit schemes are easier to implement politically because permits are allocated free to emitters. However, recognition has grown that permits can be wholly or partly auctioned, and that an emissions tax need not apply to the total amount of emissions covered (e.g. Aldy J.E et al., 2010; Goulder, 2013). Tax thresholds could exempt part of the overall amount of an emitter's liabilities, while charging the full tax rate on any extra emissions, analogous to free permits (Pezzey, 2003; Pezzey and Jotzo, 2012). Conversely, governments could auction some or all permits in an emissions trading scheme, and use the revenue to reduce other more distorting taxes and charges (Subsection 3.6.3.3), assist consumers, or pay for complementary policies.

3.8.1.2 Subsidies

Subsidies can be used as an instrument of mitigation policy by correcting market failures in the provision of low-carbon technologies and products. They have a particular role in supporting new technologies. Empirical research has shown that social rates of return on R&D can be higher than private rates of return, since spillovers are not fully internalized by the firms (see 3.11).

Subsidies are also used to stimulate energy efficiency and renewable energy production. Such subsidies do generally not fully correct negative externalities but rather support the alternatives, and are less efficient alternatives to carbon taxes and emission trading for inducing mitigation. Energy subsidies are often provided for fossil fuel production or consumption, and prove to increase emissions and put heavy burdens on public budgets (Lin and Jiang, 2011; Arze del Granado et al., 2012; Gunningham, 2013). Lowering or removing such subsidies would contribute to global mitigation, but this has proved difficult (IEA et al., 2011).

Subsidies to renewable energy and other forms of government expenditure on mitigation also have other drawbacks. First, public funds need to be raised to finance the expenditures, with well-known economic inefficiencies arising from taxation (Ballard and Fullerton, 1992). Second, subsidies, if not correcting market failures, can lead to excessive entry into, or insufficient exit from, an industry (Stigler, 1971). Third, subsidies can become politically entrenched, with the beneficiaries lobbying governments for their retention at the expense of society overall (Tullock, 1975).

Hybrids of fees and subsidies are also in use. A renewable energy certificate system can be viewed as a hybrid with a fee on energy consumption and a subsidy to renewable production (e.g., Amundsen and Mortensen, 2001). Feebates (Greene et al., 2005) involve setting an objective, such as average vehicle fuel economy; then firms or individuals that under-perform pay a fee per unit of under-performance and over-performers receive a subsidy. The incentives may be structured to generate no net revenue – the fees collected finance the subsidy.

3.8.2 Direct regulatory approaches

Prescriptive regulation involves rules that must be fulfilled by polluters who face a penalty in case of non-compliance. Examples are performance standards that specify the maximum allowable GHG emissions from particular processes or activities; technology standards that mandate specific pollution abatement technologies or production methods; and product standards that define the characteristics of potentially polluting products, including labelling of appliances in buildings, industry and the transport sector (Freeman and Kolstad, 2006).

These regulatory approaches will tend to be more suitable in circumstances where the reach or effectiveness of market-based instruments is constrained because of institutional factors, including lack of markets in emissions intensive sectors such as energy. In 'mixed economies', where parts of the economy are based on command-and-control approaches while others rely on markets, effective climate change mitigation policy will generally require a mix of market and non-market instruments.

3.8.3 Information programmes

Reductions in GHG emissions can also be achieved by providing accurate and comprehensive information to producers and consumers on the costs and benefits of alternative options. Information instruments include governmental financing of research and public statistics, and awareness-raising campaigns on consumption and production choices (Mont and Dalhammar, 2005).

3.8.4 Government provision of public goods and services, and procurement

Government funding of public goods and services may be aimed directly at reducing GHG emissions, for example, by providing infrastructures and public transport services that use energy more efficiently; promoting R&D on innovative approaches to mitigation; and removing legal barriers (Creutzig et al., 2011).

3.8.5 Voluntary actions

Voluntary agreements can be made between governments and private parties in order to achieve environmental objectives or improve environmental performance beyond compliance with regulatory obligations. They include industry agreements, self-certification, environmental management systems, and self-imposed targets. The literature is ambiguous about whether any additional environmental gains are obtained through voluntary agreements (Koehler, 2007; Lyon and Maxwell, 2007; Borck and Coglianese, 2009).

3.8.6 Policy interactions and complementarity

Most of the literature deals with the use and assessment of one instrument, or compares alternative options, whereas, in reality, numerous, often overlapping instruments are in operation (see Chapters 7–16). Multiple objectives in addition to climate change mitigation, such as energy security and affordability and technological and industrial development, may call for multiple policy instruments. Another question is whether and to what extent emissions pricing policies need to be complemented by regulatory and other instruments to achieve cost-effective mitigation, for example, because of additional market failures, as in the case of energy efficiency (Box 3.10) and technological development (3.11.1).

However, the coexistence of different instruments creates synergies, overlaps and interactions that may influence the effectiveness and costs of policies relative to a theoretical optimum (Kolstad et al., 1990; see also section 3.6 above). Recent studies have analysed interactions between tradeable quotas or certificates for renewable energy and emission trading (e.g., Möst and Fichtner, 2010; Böhringer and Rosendahl, 2010) and emissions trading and tradeable certificates for energy efficiency improvements (e.g., Mundaca, 2008; Sorrell et al., 2009) (see also Chapters 9 and 15). Similar effects occur in the overlay of other selective policy instruments with comprehensive pricing instruments. Policy interactions can also create implementation and enforcement challenges when policies are concurrently pursued by different legal or administrative jurisdictions (Goulder and Parry, 2008; Goulder and Stavins, 2011).

3.8.7 Government failure and policy failure

To achieve large emissions reductions, policy interventions will be needed. But failure is always a possibility, as shown by recent experiences involving mitigation policies (Chapters 13–16). The literature is beginning to reflect this. The failure of such policies tends to be associated with the translation of individual preferences into government action.

3.8.7.1 Rent-seeking

Policy interventions create rents, including subsidies, price changes arising from taxation or regulation and emissions permits. Private interests lobby governments for policies that maximize the value of their assets and profits. The sums involved in mitigating climate change provide incentives to the owners of assets in GHG intensive industries or technologies for low-carbon production to engage in rent-seeking.[26]

The political economy of interest group lobbying (Olson, 1971) is apparent in the implementation of climate change mitigation policies. Examples include lobbying for allocations of free permits under the emissions trading schemes in Europe (Hepburn et al., 2006; Sijm et al., 2006; Ellerman, 2010) and Australia (Pezzey et al., 2010) as well as renewable energy support policies in several countries (Helm, 2010).

To minimize the influence of rent-seeking and the risk of regulatory capture, two basic approaches have been identified (Helm, 2010). One is to give independent institutions a strong role, for example, the United Kingdom's Committee on Climate Change (McGregor et al., 2012) and Australia's Climate Change Authority (Keenan R.J et al., 2012) (see also Chapter 15).

Another approach to reducing rent-seeking is to rely less on regulatory approaches and more on market mechanisms, which are less prone to capture by special interests because the value and distribution of rents is more transparent. This may of course lead to other problems associated with regulatory design.

3.8.7.2 Policy uncertainty

One aim of climate change mitigation policy is to promote emissions-reducing investments in sectors where assets have a long economic lifespan, such as energy (Chapter 7), buildings (Chapter 9) and transport (Chapter 8). Investment decisions are mainly based on expectations about future costs and revenues. Therefore, expectations about future policy settings can be more important than current policies in determining the nature and extent of investment for mitigation (Ulph, 2013).

Uncertainty over future policy directions, including changes in existing policies arising from, say, political change, can affect investment decisions and inhibit mitigation, as well as create economic costs (Weitzman, 1980; see also Chapter 2). To achieve cost-effective mitigation actions, a stable and predictable policy framework is required.

[26] CBA takes into account that governments are social-profit maximizers, which may not necessarily be the case.

Box 3.8 Different conditions in developed and developing countries and implications for suitability of policy instruments

Differences in economic structure, institutions and policy objectives between low-income and high-income countries can mean differences in the suitability and performance of policy instruments. Overriding policy objectives in most developing countries tend to be strongly oriented towards facilitating development (Kok et al., 2008), increasing access to energy and alleviating poverty (see Chapters 4 and 14). In general, they have fewer human and financial resources, less advanced technology, and poorer institutional and administrative capacity than developed countries. This may constrain their ability to evaluate, implement and enforce policies. Further, the prerequisites for effectiveness, such as liberalized energy markets to underpin price-based emissions reduction instruments, are often lacking. Thus, the use of some policy instruments, including carbon trading schemes, can pose greater institutional hurdles and implementation costs, or not be feasible. Capacity building is therefore critical in creating mechanisms to support policy choices and implementation. Economic reform may also be needed in order to remove distortions in regulatory and pricing mechanisms and enable effective mitigation policies to be devised and implemented.

The opportunity cost of capital, and of government resources in particular, may be higher in developing countries than in developed countries. Consequently, the payoff from mitigation policies needs to be higher than in developed countries in order for mitigation investment to be judged worthwhile. Thus, developing countries may require international financial assistance in order to support their mitigation activities or make them economically viable.

3.9 Metrics of costs and benefits

This Section focuses on conceptual issues that arise in the quantification and measurement, using a common metric, of the pros and cons associated with mitigation and adaptation (i.e., benefits and costs). How costs are balanced against benefits in evaluating a climate policy is a matter for ethics, as has repeatedly been emphasized in this Chapter. The discussion is largely based on the economic paradigm of balancing costs against benefits, with both measured in monetary units. But leaving aside monetary units, the underlying information can be helpful for policy makers who adopt other ethical perspectives. This Section is also relevant for methods that reduce performance to a small number of metrics rather than a single one (such as MCA).

We begin with the chain of cause and effect. The chain starts with human activity that generates emissions which may be reduced with mitigation (recognizing that nature also contributes to emissions of GHGs). The global emissions of GHGs lead to changes in atmospheric concentrations, then to changes in radiative forcing, and finally to changes in climate. The latter affect biological and physical systems in good as well as bad ways (including through impacts on agriculture, forests, ecosystems, energy generation, fire and floods). These changes in turn affect human wellbeing, negatively or positively, with both monetary and other consequences.[27] Each link in the chain has a time dimension, since emissions at a particular point in time lead to radiative forcing at future points in time, which later lead to more impacts and damages. The links also have spatial dimensions. Models play a key role in defining the relationships between the links in the chain. Global Climate Models (GCMs) translate emissions through atmospheric concentrations and radiative forcing into changes in climate. Other models – including crop, forest growth and hydrology models – translate changes in climate into physical impacts. Economic models translate those impacts into measures

[27] We refer to effects on biological and physical systems as 'impacts', and effects of those impacts on human wellbeing as 'damages', whether positive or negative. These effects may include non-human impacts that are of concern to humans (see also Subsections 3.4.1 and 3.4.3).

that reflect a human perspective, typically monetary measures of welfare loss or gain. GCMs aggregate emissions of various gases into an overall level of radiative forcing; hydrology models aggregate precipitation at multiple locations within a watershed into stream flow at a given location; economic models aggregate impacts into an overall measure of welfare loss.

Much of the literature on impacts focuses on particular types of impacts at particular locations. Another aspect involves metrics that allow differential regulation of different GHGs. For instance, the relative weight that regulators should place on CH_4 and CO_2 in mitigation strategies. Because impacts and damages are so poorly known it has proved surprisingly difficult to provide a rigorous answer to that question.

3.9.1 The damages from climate change

The impacts of climate change may benefit some people and harm others. It can affect their livelihood, health, access to food, water and other amenities, and natural environment. While many non-monetary metrics can be used to characterize components of impacts, they provide no unambiguous aggregation methods for characterizing overall changes in welfare. In principle, the economic theory of monetary valuation provides a way, albeit an imperfect one, of performing this aggregation and supporting associated policy-making processes.

Changes that affect human wellbeing can be 'market' or 'non-market' changes. Market effects involve changes in prices, revenue and net income, as well as in the quantity, quality or availability of market commodities. Key is the ability to observe both prices and how people respond to them when choosing quantities to consume. Non-market changes involve the quantity, quality or availability of things that matter to people and which are not obtained through the market (e.g., quality of life, culture and environmental quality). A change in a physical or biological system can generate both market and non-market damage to human wellbeing. For example, an episode of extreme heat in a rural area may cause farm labourers heat stress and dry up a wetland that serves as a refuge for migratory birds, while killing some crops and impairing the quality of others. From an economic perspective, damages would be conceptualized as a loss of income for farmers and farm workers, an increase in crop prices for consumers and a reduction in their quality; and non-market impacts might include the impairment of the ecosystem and human health (though some health effects may be captured in the wages of farm workers).

Economists define value in terms of a 'trade-off'. As discussed in Subsection 3.6.1 , the economic value of an item, measured in money terms, is defined as the amount of income that would make a person whole, either in lieu of the environmental change or in conjunction with the environmental change; that is, its 'income equivalent'. This equivalence is evaluated through the Willingness To Pay (WTP) and Willingness To Accept (WTA) compensation measures (see also Willig, 1976; Hanemann, 1991). The item in question may or may not be a marketed commodity: it can be *anything* that the person values. Thus, the economic value of an item is *not* in general the same as its price or the total expenditure on it. The economic concept of value based on a trade-off has some critics. The item being valued may be seen as incommensurable with money, such that no trade-off is possible. Or, the trade-off may be deemed inappropriate or unethical (e.g., Kelman, 1981; see also Jamieson, 1992; Sagoff, 2008). In addition, while the economic concept of value is defined for an individual, it is typically measured for aggregates of individuals, and the issue of equity-weighting is often disregarded (Nyborg, 2012 see also Subsection 3.5.1.3).[28]

[28] The use of the term "willingness" in WTP and WTA should not be taken literally. For instance, individuals may have a willingness to pay for cleaner air (the reduction in income that would be equivalent in welfare terms to an increase in air quality) but they may be very unwilling to make that payment, believing that clean air is a right that should not have to be purchased.

The methods used to measure WTP and WTA fall into two categories, known as 'revealed preference' and 'stated preference' methods. For a marketed item, an individual's purchase behaviour reveals information about his value of it. Observation of purchase behaviour in the marketplace is the basis of the revealed preference approaches. One can estimate a demand function from data on observed choice behaviour. Then, from the estimated demand function, one can infer the purchaser's WTP or WTA values for changes in the price, quantity, quality or availability of the commodity. Another revealed preference approach, known as the hedonic pricing method, is based on finding an observed relationship between the quality characteristics of marketed items and the price at which they are sold (e.g., between the price of farmland and the condition and location of the farmland). From this approach, one can infer the 'marginal' value of a change in characteristics.[29] For instance, some have attempted to measure climate damages using an hedonic approach based on the correlation of residential house prices and climate in different areas (Cragg and Kahn, 1997; Maddison, 2001, 2003; Maddison and Bigano, 2003; Rehdanz and Maddison, 2009). The primary limitation of revealed preference methods is the frequent lack of a market associated with the environmental good being valued.

With stated preference, the analyst employs a survey or experiment through which subjects are confronted with a trade-off. With contingent valuation, for example, they are asked to choose whether or not to make a payment, such as a tax increase that allows the government to undertake an action that accomplishes a specific outcome (e.g., protecting a particular ecosystem). By varying the cost across subjects and then correlating the cost offered with the percentage of 'yes' responses, the analyst traces out a form of demand function from which the WTP (or WTA) measure can be derived. With choice experiments, subjects are asked to make repeated choices among alternative options that combine different outcomes with different levels of cost.[30] Although a growing number of researchers use stated preference studies to measure the public's WTP for climate mitigation, one prominent criticism is the hypothetical nature of the choices involved.[31]

All these methods have been applied to valuing the damages from climate change.[32] AR2 contained a review of the literature on the economic valuation of climate change impacts. Since then, the literature has grown exponentially. The economic methodology has changed little (except for more coverage of non-market impacts and more use of stated preference). The main change is in the spatial representation of climate change impacts; whereas the older literature tended to measure the economic consequences of a uniform increase of, say 2.5^{o}C across the United States, the recent literature uses downscaling to measure impacts on a fine spatial scale. Most of the recent literature

[29] Details of these methods can be found in Becht (1995), chapters by McConnell and Bockstael (2006), Palmquist (2006), Phaneuf and Smith (2006), Mäler and Vincent (2005), or in textbooks such as Kolstad (2010), Champ, Boyle and Brown (2003), Haab and McConnell (2002) or Bockstael and McConnell (2007).

[30] Details can be found in Carson and Hanemann (2005), or in textbooks such as Champ, Boyle and Brown (2003), Haab and McConnell (2002) and Bennett and Blamey (2001).

[31] Examples include Berrens et al. (2004), Lee and Cameron (2008), Solomon and Johnson (2009), and Aldy et al. (2012) for the U.S.; Akter and Bennett (2011) for Australia; Longo et al. (2012) for Spain; Lee et al. (2010) for Korea; Adaman et al. (2011) for Turkey; and Carlsson et al. (2012) for a comparative study of WTP in China, Sweden and the US.

[32] Other economic measures of damage are sometimes used that may not be appropriate. The economic damage is, in principle, the lesser of the value of what was lost or the cost of replacing it (assuming a suitable and appropriate replacement exists). Therefore, the replacement cost itself may or may not be a relevant measure. Similarly, if the cost of mitigation is actually incurred, it is a lower bound on the value placed on the damage avoided. Otherwise, the mitigation cost is irrelevant if nobody is willing to incur it.

on the economic valuations of climate change has focused on market impacts, especially impacts on agriculture, forestry, sea level, energy, water and tourism. [33]

The most extensive economic literature pertains to agriculture. The demand for many such commodities is often inelastic, so the short-run consequence of a negative supply shock is a price increase; while a benefit to producers, it is harmful for consumers (Roberts and Schlenker, 2010; Lobell et al., 2011). Some studies measure the effect of weather on current profits, rather than that of climate on long-term profitability (e.g., Deschênes and Greenstone, 2007), and some explore the effect of both weather and climate on current profits (Kelly et al., 2005). Examining weather and climate simultaneously leads to difficulties in identifying the separate effects of weather and climate (Deschênes and Kolstad, 2011), as well as in dealing with the confounding effects of price changes (Fisher et al., 2012). While some recent studies have found that extreme climate events have a disproportionate impact on agricultural systems (Schlenker and Roberts, 2009; Lobell et al., 2011; Deschênes and Kolstad, 2011; see also WGII, sec. 7.3.2.1), the relatively high degree of spatial or temporal aggregation means that those events are not well captured in many existing economic analyses. Another difficulty is the welfare significance of shifts in location of agricultural production caused by climate. Markets for agricultural commodities are national or international in scope, so some economic analyses focus on aggregate international producer and consumer welfare. Under the potential Pareto criterion, transfers of income from one region to another are of no welfare significance, though of real policy significance.[34]

With other market sectors, the literature is both sparse and highly fragmented, but includes some estimates of economic impacts of climate change on energy, water, sea level rise, tourism and health in particular locations. With regard to energy, climate change is expected to reduce demand for heating and increase demand for cooling (see WGII AR5, ch. 10). Even if those two effects offset one another, the economic cost need not be negligible. With water supply, what matters in many cases is not total annual precipitation but the match between the timing of precipitation and the timing of water use (Strzepek and Boehlert, 2010). Those questions require analysis on a finer temporal or spatial scale than has typically been employed in the economic damage literature.

Estimates of the economic costs of a rise in sea level generally focus on either the property damage from flooding or on the economic costs of prevention, for example, sea wall construction (Hallegatte et al., 2007; Hallegatte, 2008; 2012). They sometimes include costs associated with the temporary disruption of economic activity. They typically do not measure the loss of wellbeing for people harmed or displaced by flooding.[35] Similarly, the economic analyses of climate change impacts on tourism have focused on changes, for example, in the choice of destination and the income from tourism activities attributable to an increase in temperature, but not on the impacts on participants' wellbeing.[36]

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[33]While there is a large literature covering physical and biological impacts, except for agriculture and forestry only a tiny portion of the literature carries the analysis to the point of measuring an economic value. However, the literature is expanding. A *Web of Knowledge* search on the terms ("climate change" or "global warming") and "damage" and "economic impacts" returns 39 papers for pre-2000, 136 papers for 2000-2009 and 209 papers for 2010 through September 2013.

[34]The same issue arises with the effects on timber production in a global timber market; see for example, Sohngen et al. (2001).

[35] Exceptions include Daniel et al. (2009) and Botzen and van den Bergh (2012). Cardoso and Benhin (2011) provide a stated preference valuation of protecting the Columbian Caribbean coast from sea level rise.

[36]Exceptions include Pendleton and Mendelsohn (1998), Loomis and Richardson (2006), Richardson and Loomis (2004), Pendleton et al. (2011), Tseng and Chen (2008), and for commercial fishing, Narita et al (2012).

The economic metrics conventionally used in the assessment of non-climate health outcomes have also been used to measure the impact of climate on health (e.g., Deschênes and Greenstone, 2011; Watkiss and Hunt, 2012). Measures to reduce GHGs may also reduce other pollutants associated with fossil fuel combustion, such as NO_x and particulates, which lead to time lost from work and reduced productivity (Östblom and Samakovlis, 2007). Exposure to high ambient temperatures is known to diminish work capacity and reduce labour productivity.[37]

3.9.2 Aggregate climate damages

This Subsection focuses on the aggregate regional and global economic damages from climate change as used in IAMs to balance the benefits and costs of mitigation on a global scale.

The first estimates of the economic damage associated with a specific degree of climate change were made for the United States (Smith and Tirpak, 1989; Nordhaus, 1991; Cline, 1992; Titus, 1992; Fankhauser, 1994). These studies involved static analyses estimating the damage associated with a particular climate end-point, variously taken to be a 1°C, 2.5°C or 3°C increase in global average annual temperature. This approach gave way to dynamic analyses in IAMs that track economic output, emissions, atmospheric CO_2 concentration and damages. Because IAMs examine costs and benefits for different levels of emissions, they need damage 'functions' rather than point estimates.

Three IAMs have received most attention in the literature, all developed in the 1990s. The DICE model was first published in Nordhaus (1993a; b) but had its genesis in Nordhaus (1977); its regionally disaggregated sibling RICE was first published by Nordhaus and Yang (1996).[38] The FUND model was first published in Tol (1995). And the PAGE model, developed for European decision makers, was first published in Hope et al. (1993) and was used in the Stern (2007) review.[39] The models have undergone various refinements and updates.[40] While details have changed, their general structure has stayed the same, and questions remain about the validity of their damage functions (see Pindyck, 2013).

The IAMs use a highly aggregated representation of damages. The spatial unit of analysis in DICE is the entire world, whereas it is divided into 12 broad regions in RICE, 16 regions in FUND, and eight in PAGE. DICE and RICE have a single aggregate damage function for the change in global or regional GDP as a function of the increase in global average temperature, here denoted ΔT_t, and sea-level rise (which in turn is modelled as a function of ΔT_t). PAGE has four separate damage functions for different types of damages in each region: economic, non-economic, sea-level rise, and climate discontinuity (as a function of ΔT_t and the derivative rise in sea level). FUND has eight sectoral damage functions for each region, with each damage dependent on the regional ΔT_t and, in some cases, the rate of change in ΔT_t. Adaptation and catastrophic damage are included in a very simple way in some models (Greenstone et al., 2013) .

[37] See Kjellstrom et al. (2009), Zivin and Neidell (2010), or Dunne et al (2013). Some recent studies have focused on the correlation between high temperatures and poverty (Nordhaus, 2006), the link between fluctuations in temperature, cyclones and fluctuations in economic activity (Dell et al., 2009, 2012; Hsiang, 2010), and the connection between climate change and human conflict (Hsiang et al., 2013).

[38] There are many extensions of DICE, including AD-DICE (de Bruin et al., 2009), with a more explicit treatment of adaptation.

[39] Some other IAMs have damage functions, including the MERGE Model (Manne and Richels, 1992, 1995, 2004a); the CETA model (Peck and Teisberg, 1992, 1994); and, more recently, several IAMs developed by European researchers including the WITCH model (Bosetti et al., 2006), its extension the AD-WITCH model (Bosello et al., 2010), the ENVISAGE model (Roson and Mensbrugghe, 2012), and a model developed by Eboli et al. (2010) and Bosello et al. (2012).

[40] The most recent versions are: DICE2013 (Nordhaus and Sztorc, 2013); RICE2010 (Nordhaus, 2010); PAGE 2009 (Hope, 2011, 2013); FUND 3.7 (Anthoff and Tol, 2013).

Let D_{jkt} denote damages of type *j* in year *t* and region *k*, expressed as a proportion of per capita GDP in that year and region, Y_{kt}. The damage functions, say $D_{jkt} = D_{jkt}(\Delta T_t)$ are calibrated based on: (1) the modeller's choice of a particular algebraic formula for $D_{jkt}(\Delta T_t)$: (2) the common assumption of zero damage at the origin [$D_{jkt}(0)=0$]; and (3) the modeller's estimate of damages at a benchmark change in global average temperature, ΔT* (typically associated with a doubling of atmospheric CO_2). For example, in PAGE and DICE the damage function resolves into a power function:

Equation 3.9.1. $$D_{jt} = a_j[\Delta T_t/\Delta T^*]^b Y_t$$

where *b* is a coefficient estimated or specified by the modeller, and a_j is the modeller's estimate of the economic damage for the benchmark temperature change.[41] In DICE, b = 2 is chosen.[42] In PAGE, *b* is a random variable between 1.5 and 3. In FUND, the damage functions are deterministic but have a slightly more complicated structure and calibration than in Equation 3.9.1.

Because each damage function is convex (with increasing marginal damage), the high degree of spatial and temporal aggregation causes the model to understate aggregate damages. This can be seen by representing the spatial or temporal distribution of warming by a mean and variance, and writing expected damages in a second order expansion around the mean.

A concern may be whether the curvature reflected in Equation 3.9.1 is adequate. The functions are calibrated to the typical warming associated with a doubling of CO_2 concentration, along with associated damage. The aggregate damage is based on heroic extrapolations to a regional or global scale from a sparse set of studies (some from the 1990s) done at particular geographic locations. The impacts literature is now paying somewhat more attention to higher levels of warming (New et al. (2011), World Bank (2012), and WG2 sec. 19.5.1), though estimates of monetary damage remain scarce (however, the literature is expanding rapidly). Another concern is the possibility of tipping points and extreme events (Lenton et al., 2008), possibly including increases in global temperature as large as 10–12°C that are not always reflected in the calibration (Sherwood and Huber, 2010).

The economic loss or gain from warming in a given year typically depends on the level of warming in that same year, with no lagged effects (at least for damages other than sea-level rise in DICE, the non-catastrophe component of damages in PAGE, and some sectors of FUND). Thus, impacts are (a) reversible, and (b) independent of the prior trajectory of temperatures. This assumption simplifies the computations, but some impacts and damages may actually depend on the rate of increase in temperature.[43] The optimal trajectory of mitigation and the level of damages could also depend on the cumulative amount of warming in previous years (measured, say, in degree years).

DICE, FUND and PAGE represent damage as a change in production of market commodities that is proportional to output (a 'multiplicative' formulation). Weitzman (2010a) finds that this specification matters with high levels of warming because an additive formulation leads to more drastic emission reduction. Besides affecting current market production, climate change could damage natural, human or physical capital (e.g., through wildfires or floods). Damage to capital stocks may last beyond a year and have lingering impacts that are not captured in current formulations (Wu et al., 2011). Economic consequences depend on what is assumed about the elasticity of substitution in the utility function between market commodities and non-market climate impacts. An elasticity of substitution of unity is equivalent to the conventional multiplicative formulation, but a value less than unity, generates a more drastic trajectory of emission reductions (Krutilla, 1967; Sterner and Persson, 2008).

[41] Typically, ΔT* is 2.5 or 3 °C. When $\Delta T_t = \Delta T^*$ in this equation, then $D_{jt} = a_j Y_t$.

[42] This formulation is also used by Kandlikar (1996a) and Hammitt et al. (1996a) with *b* = 1, 2 or 3.

[43] This rate of change was considered by Manne and Richels (2004a) in MERGE and by Peck and Teisberg (1994) in CETA. The latter found that it can have quite a large effect on the size of the optimal carbon tax.

The utility function in these three IAMs does not distinguish between the welfare gains deriving from risk reduction when people are risk averse versus the gains from smoothing consumption over time when people have declining marginal utility of income: both preferences are captured by the curvature of the utility function as measured by η, in Equation 3.6.4. However, Kreps and Porteus (1978) and Epstein and Zin (1991) show that two separate functions can have separate parameters for risk aversion and inter-temporal substitution. This formulation is used successfully in the finance literature to explain anomalies in the market pricing of financial assets, including the equity premium (Campbell, 1996; Bansal and Yaron, 2004). The insight from this literature is that the standard model of discounted expected utility, used in DICE, FUND and PAGE, sets the risk premium too low and the discount rate too high, a result confirmed by Ackerman et al. (2013) and Crost and Traeger (2013).

Our general conclusion is that the reliability of damage functions in current IAMs is low. Users should be cautious in relying on them for policy analysis: some damages are omitted, some estimates may not reflect the most recent information on physical impacts; the empirical basis of estimates is sparse and not necessarily up-to-date; and adaptation is difficult to properly represent. Furthermore, the literature on economic impacts has been growing rapidly and is often not well represented in damage functions used in IAMs. Some authors (e.g., WGII, ch. 19) conclude these damage functions are biased downwards. It should be underscored that most IAMs used in Chapter 6 of this volume do not consider damage functions so this particular criticism does not apply to Chapter 6 analyses.

Box 3.9 Uncertainty and damages: the fat tails problem

Weitzman (2009, 2011) has drawn attention to what has become known as the fat-tails problem. He emphasized the existence of a chain of structural uncertainties affecting both the climate system response to radiative forcing and the possibility of some resulting impacts on human wellbeing that could be catastrophic. Uncertainties relate to both means of distribution and variances. The resulting compounded probability distribution of possible economic damage could have a fat bad tail: i.e., the likelihood of an extremely large reduction in wellbeing does not go quickly to zero.[44] With or without risk aversion, the expected marginal reduction in wellbeing associated with an increment in emissions today could be very large, even infinite.[45] See also Section 2.5.3.3.

A policy implication of this is that tail events can become much more important in determining expected damage than would be the case with probability distributions with thinner tails. Weitzman (2011) illustrates this for the distribution of temperature consequences of a doubling of atmospheric CO_2 (climate sensitivity), using IPCC WG1 estimates to calibrate two distributions, one fat-tailed and one thin-tailed, to have a median temperature change of 3°C and a 15% probability of a temperature change in excess of 4.5°C. With this calibration, the probability of temperatures in excess of 8°C is nearly ten times greater with the fat-tailed distribution than the thin-tailed distribution. If high consequence, low probability events become more likely at higher temperatures, then tail events can dominate the computation of expected damages from climate change, depending on the nature of the probability distribution and other features of the problem (including timing and discounting).

[44] Weitzman (2009) defines a fat tailed distribution as one with an infinite moment generating function (a thin-tailed distribution has a finite moment generating function); more intuitively, for a fat-tailed distribution, the tail probability approaches zero more slowly than exponentially. For example, the normal (and any distribution with finite support) would be thin-tailed whereas the Pareto distribution (a power law distribution) would be fat-tailed.

[45] Weitzman (2007b, 2009) argued that it could be infinite. His results have been challenged by some as too pessimistic, e.g., Nordhaus (2011a), Pindyck (2011) and Costello et al. (2010).

At a more technical level, with some fat-tailed distributions and certain types of utility functions (constant relative risk aversion), the expectation of a marginal reduction in wellbeing associated with an increment in emissions is infinite. This is because in these cases, marginal utility becomes infinite as consumption goes to zero. This is a troubling result since infinite marginal damage implies all available resources should be dedicated to reducing the effects of climate change. But as Weitzman himself and other authors have pointed out, this extreme result is primarily a technical problem which can be solved by bounding the utility function or using a different functional form.

The primary conclusion from this debate is the importance of understanding the impacts associated with low probability, high climate change scenarios. These may in fact dominate the expected benefits of mitigation.

The policy implication of this is that the nature of uncertainty can profoundly change how climate policy is framed and analysed with respect to the benefits of mitigation. Specifically, fatter tails on probability distributions of climate outcomes increase the importance in understanding and quantifying the impacts and economic value associated with tail events (such as 8°C warming). It is natural to focus research attention on most likely outcomes (such as a 3°C warming from a CO_2 doubling), but it may be that less likely outcomes will dominate the expected value of mitigation.

3.9.3 The aggregate costs of mitigation

Reductions in GHG emission often impose costs on firms, households and governments as a result of changes in prices, revenues and net income, and in the availability or quality of commodities. GHG reduction requires not only technological but also behavioural and institutional changes, which may affect wellbeing. The changes in wellbeing are measured in monetary terms through a change in income that is equivalent to the impact on wellbeing. Changes in prices and incomes are often projected through economic models (see Chapter 6). In many cases, mitigation primarily involves improvements in energy efficiency or changes in the generation and use of energy from fossil fuels in order to reduce GHG emissions.

The models assessed in Chapter 6 are called IAMs (or Integrated Models – IMs) because they couple several systems together (such as the economy and the climate) in an integrated fashion, tracking the impact of changes in economic production on GHG emissions, as well as of emissions on global temperatures and the effect of mitigation policies on emissions. As discussed in Section 6.2, the IAMs used in Chapter 6 are heterogeneous. However, for most of the Chapter 6 IAMs, climate change has no feedback effects on market supply and demand, and most do not include damage functions.[46] The calculation of cost depends on assumptions made (1) in specifying the model's structure and (2) in calibrating its parameters. The models are calibrated to actual economic data. While more validation is required, some models are validated by making and testing predictions of the response to observed changes (Valenzuela et al., 2007; Beckman et al., 2011; Baldos and Hertel, 2013). While some models do not address either the speed or cost of adjustment, many models incorporate adjustment costs and additional constraints to reflect deviations from full optimization (see Jacoby et al., 2006; Babiker et al., 2009; van Vuuren et al., 2009). Most models allow little scope for endogenous (price-induced) technical change (3.11.4) or endogenous non-price behavioural factors (3.10.1). It is a matter of debate how well the models accurately represent underlying economic processes (see Burtraw, 1996; Burtraw et al., 2005; Hanemann, 2010).

Besides estimating total cost, the models can be used to estimate Marginal Abatement Cost (MAC), the private cost of abating one additional unit of emissions. With a cap-and-trade system, emissions would theoretically be abated up to the point where MAC equals the permit price; with an emissions

[46] Climate is assumed to be *separable* from market goods in the models' utility functions. If that assumption is incorrect, Carbone and Smith (2013) show that the welfare calculation may have significant error.

tax, they would be abated to the point where MAC equals the tax rate. It is common to graph the MAC associated with different levels of abatement. Under simplified conditions, the area under the MAC curve measures the total economic cost of emissions reduction, but not if it fails to capture some of the economy-wide effects associated with large existing distortions (Klepper and Peterson, 2006; Paltsev et al., 2007; Kesicki and Ekins, 2012; Morris et al., 2012). However, a MAC is a static approximation to the dynamic process involved in pollution abatement; it thus has its limitations.

Box 3.10 Could mitigation have a negative private cost?

A persistent issue in the analysis of mitigation options and costs is whether available mitigation opportunities can be privately profitable – that is, generate benefits to the consumer or firm that are in excess of their own cost of implementation – but which are not voluntarily undertaken. Absent another explanation, a negative private cost implies that a person is not fully pursuing his own interest. (By contrast, a negative social cost arises when the total of everybody's benefits exceeds costs, suggesting that some private decision-maker is not maximizing the interests of others.) The notion that available mitigation opportunities may have negative costs recently received attention because of analyses by McKinsey & Company (2009), Enkvist et al. (2007) and others that focused especially on energy use for lighting and heating in residential and commercial buildings, and on some agricultural and industrial processes. Much of this literature is in the context of the "energy efficiency gap,"[47] which dates to the 1970s, and the "Porter hypothesis".[48]

The literature suggesting that available opportunities may have negative cost often points to institutional, political or social barriers as the cause. But other literature suggests economic explanations. In addition, however, evidence indicates that the extent of such negative cost opportunities can be overstated, particularly in purely engineering studies.

Engineering studies may overestimate the energy savings, for example because they assume perfect installation and maintenance of the equipment (Dubin et al., 1986; Nadel and Keating, 1991) or they fail to account for interactions among different investments such as efficient lighting and cooling (Huntington, 2011). Engineering studies also may fail to account for all costs actually incurred, including time costs, scarce managerial attention and the opportunity cost of the money, time or attention devoted to energy efficiency.[49] In some cases, the engineering analysis may not account for reductions in quality (e.g., CFL lighting is perceived as providing less attractive lighting services). Choices may also be influenced by uncertainty (e.g., this is an unfamiliar product, one doesn't know how well it will work, or what future energy prices will be). Another consideration sometimes overlooked in engineering analyses is the rebound effect – the cost saving induces a higher rate of equipment usage (see Subsection 3.9.5). The analyses may overlook heterogeneity among consumers: what appears attractive for the average consumer may not be attractive for all (or many)

[47] The efficiency gap is defined as the difference between the socially desirable amount of energy efficiency (however defined) and what firms and consumers are willing to undertake voluntarily (see Meier and Whittier, 1983; Joskow and Marron, 1992, 1993; Jaffe and Stavins, 1994).

[48] Porter (1991) and Porter and van der Linde (1995) argued that unilateral reductions in pollution could stimulate innovation and improve firms' competitiveness as a by-product; see also Lanoie et al (2008); Jaffe and Palmer (1997). The subsequent literature has obtained mixed finding (Ambec and Barla, 2006; Ambec et al., 2013).

[49] For example, Anderson and Newell (2004) examined energy audits for manufacturing plants and found that roughly half of the projects recommended by auditors were not adopted despite extremely short payback periods. When asked, plant managers responded that as much as 93 percent of the projects were rejected for economic reasons, many of which related to high opportunity costs. Joskow and Marron (1992, 1993) show some engineering estimates understated actual costs.

consumers, based on differences in their circumstances and preferences. One approach to validation is to examine energy efficiency programs and compare ex ante estimates of efficiency opportunities with ex post accomplishment; the evidence from such comparisons appears to be inconclusive, though more analysis may be fruitful.[50]

Economic explanations include the following.[51] Given uncertainty and risk aversion, consumers may rationally desire a higher return as compensation. Price uncertainty and the irreversibility of investment may also pose additional economic barriers to the timing of adoption – it may pay to wait before making the investment (Hassett and Metcalf, 1993; Metcalf, 1994). Mitigation investments take time to pay off, and consumers act as if they are employing high discount rates when evaluating such investments (Hausman, 1979). These consumer discount rates might be much higher than those of commercial businesses, reflecting liquidity and credit constraints. The durability of the existing capital stock can be a barrier to rapid deployment of otherwise profitable new technologies. Also, a principal-agent problem arises when the party that pays for an energy-efficiency investment doesn't capture all the benefits, or vice versa. For example a tenant installs an efficient refrigerator, but the landlord retains ownership when the tenant leaves (split incentives). Or the landlord buys a refrigerator but doesn't care about its energy efficiency. Such problems can also arise in organizations where different actors are responsible, say, for energy bills and investment accounts.[52] Finally, energy users, especially residential users, may be uninformed, or poorly informed, about the energy savings they are forgoing. In some cases, the seller of the product has better information than the potential buyer (asymmetric information) and may fail to convey that information credibly (Bardhan et al., 2013).

Recently, some economists have suggested that systematic behavioral biases in decision making can cause a failure to make otherwise profitable investment. These have been classified as non-standard beliefs (e.g., incorrect assessments of fuel savings - Allcott, 2013), non-standard preferences (e.g., loss aversion - Greene et al., 2009), and non-standard decision-making (e.g., tax salience - Chetty et al., 2009). Such phenomena can give rise to what might be considered "misoptimization" by decision makers, which in turn could create a role for efficiency-improving policy not motivated by conventional market failures (Allcott et al., forthcoming); see Subsection 3.10.1 for a fuller account.

In summary, whether opportunities for mitigation at negative private cost exist is ultimately an empirical question. Both economic and non-economic reasons can explain why they might exist, as noted in recent reviews (Huntington, 2011; Murphy and Jaccard, 2011; Allcott and Greenstone, 2012; Gillingham and Palmer, 2014). But, evidence also suggests that the occurrence of negative private costs is sometimes overstated, for reasons identified above. This remains an active area of research and debate.

3.9.4 Social cost of carbon

Although estimates of aggregate damages from climate change are useful in formulating GHG mitigation policies (despite the caveats listed in Subsection 3.9.2), they are often needed for more mundane policy reasons. Governments have to make decisions about regulation when implementing

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[50] Arimura et al (2012) review US electricity industry conservation programs (demand side management – DSM) and conclude that programs saved energy at a mean cost of US$0.05 per kWh, with a 90% confidence interval of US$0.003 to US$0.010. Allcott and Greenstone (2012) conclude that this average cost is barely profitable. Although this may be true, one cannot conclude that on this evidence alone that ex ante engineering estimates of costs were too optimistic.

[51] Allcott and Greenstone (2012) and Gillingham and Palmer (2014) provide excellent reviews.

[52] Davis (2011) and Gillingham et al (2012) provide evidence of principal-agent problems in residential energy, although amount of energy lost as a result was not large in the cases examined.

energy policies, such as on fuel or EE standards for vehicles and appliances. The social cost of carbon emissions can be factored into such decisions.

To calculate the social cost, consider a baseline trajectory of emissions (E_0,…,E_t) that results in a trajectory of temperature changes, ΔT_t. Suppose a damage function for year *t* is discounted to the present and called $D(\Delta T_t)$, as discussed in Equation 3.9.2. These trajectories result in a discounted present value of damages:

Equation 3.9.2. $$PVD \equiv \int_0^\infty D(\Delta T_t)dt$$

Then take the derivative with respect to a small change in emissions at t=0, E_0, to measure the extra cost associated with a one tonne increase in emissions at time 0 (that is, the increment in *PVD*):

Equation 3.9.3. $$MDCC = \frac{\partial PVD}{\partial E_0}.$$

When applied to CO_2 this equation gives the marginal damage from the change in climate that results from an extra tonne of carbon. It is also called the social cost of carbon (SCC). It should be emphasized that the calculation of SCC is highly sensitive to the projected future trajectory of emissions and also any current or future regulatory regime.[53]

Because of its potential use in formulating climate or energy regulatory policy, governments have commissioned estimates of SCC. Since 2002, an SCC value has been used in policy analysis and regulatory impact assessment in the United Kingdom (Clarkson and Deyes, 2002). It was revised in 2007 and 2010. In 2010, a standardized range of SCC values based on simulations with DICE, FUND and PAGE using alternative projections of emissions and alternative discount rates, was made available to all U.S. Government agencies.[54] It was updated in 2013 (US Interagency Working Group, 2013).

3.9.5 The Rebound effect

Technological improvements in energy efficiency (EE) have direct effects on energy consumption and thus GHG emissions, but can cause other changes in consumption, production and prices that will, in turn, affect GHG emissions. These changes are generally called 'rebound' or 'takeback' because in most cases they reduce the net energy or emissions reduction associated with the efficiency improvement. The size of rebound is controversial, with some research papers suggesting little or no rebound and others concluding that it offsets most or all reductions from EE policies (Greening et al., 2000; Binswanger, 2001; Gillingham et al., 2013, summarize the empirical research). Total EE rebound can be broken down into three distinct parts: substitution-effect, income-effect and economy-wide.

In end-use consumption, substitution-effect rebound, or 'direct rebound' assumes that a consumer will make more use of a device if it becomes more energy efficient because it will be cheaper to use. Substitution-effect rebound extends to innovations triggered by the improved EE that results in new ways of using the device. To pay for that extra use, the individual must still consume less of something else, so net substitution-effect rebound is the difference between the energy expended

[53] Some ambiguity regards the definition of the SCC and the correct way to calculate it in the context of an equilibrium IAM (in terms of distinguishing between a marginal change in welfare vs. a marginal change in damage only). See, for instance, an account of the initial U.S. Government effort (Greenstone et al., 2013).

[54] Obviously, estimates of the SCC are sensitive to the structural and data assumptions in the models used to compute the SCC. Weitzman (2013), for instance, demonstrates the significance of the discount rate in the calculation.

in using more of the device and the energy saved from using whatever was previously used less (see Thomas and Azevedo, 2013).

Income-effect rebound or ‘indirect rebound’, arises if the improvement in EE makes the consumer wealthier and leads her to consume additional products that require energy. Even if energy efficient bulbs lead to no substitution-effect rebound (more lighting), income-effect rebound would result if the consumer spends the net savings from installing the bulbs on new consumption that uses energy. The income-effect rebound will reflect the size of the income savings from the EE improvement and the energy intensity of marginal income expenditures.

Analogous rebound effects for EE improvements in production are substitution towards an input with improved energy efficiency, and substitution among products by consumers when an EE improvement changes the relative prices of goods, as well as an income effect when an EE improvement lowers production costs and creates greater wealth.

Economy-wide rebound refers to impacts beyond the behaviour of the entity benefiting directly from the EE improvement, such as the impact of EE on the price of energy. For example, improved fuel economy lowers vehicle oil demand and prices leading some consumers to raise their consumption of oil products. The size of this energy price effect will be greater with less elastic supply and more elastic demand. Some argue that the macroeconomic multiplier effects of a wealth shock from EE improvement also create economy-wide rebound.

Rebound is sometimes confused with the concept of economic leakage, which describes the incentive for emissions-intensive economic activity to migrate away from a region that restricts GHGs (or other pollutants) towards areas with fewer or no restrictions on such emissions. Energy efficiency rebound will occur regardless of how broadly or narrowly the policy change is adopted. As with leakage, however, the potential for significant rebound illustrates the importance of considering the full equilibrium effects of a policy designed to address climate change.

3.9.6 Greenhouse gas emissions metrics

The purpose of emissions metrics is to establish an exchange rate, that is, to assign relative values between physically and chemically different GHGs and radiative forcing agents (Fuglestvedt et al., 2003; Plattner et al., 2009). For instance, per unit mass, CH_4 is a more potent GHG than CO_2 in terms of instantaneous radiative forcing, yet it operates on a shorter time scale. In a purely temporal sense, the impacts are different. Therefore, how should mitigation efforts be apportioned for emissions of different GHGs?[55]

GHG emissions metrics are required for generating aggregate GHG emissions inventories; to determine the relative prices of different GHGs in a multi-gas emissions trading system; for designing multi-gas mitigation strategies; or for life-cycle assessment (e.g., Peters, Aamaas, Lund, et al., 2011). Since metrics quantify the trade-offs between different GHGs, any metric used for mitigation strategies explicitly or implicitly evaluates the climate impact of different gases relative to each other.

The most prominent GHG emissions metric is the Global Warming Potential (GWP), which calculates the integrated radiative forcing from the emission of one kilogram of a component *j* out to a time horizon *T*:

Equation 3.9.4. $$AGWP_j(T) = \int_0^T RF_j(t)\,dt,$$

The AGWP is an absolute metric. The corresponding relative metric is then defined as $GWP_j = AGWP_j / AGWP_{CO2}$.

[55] This issue is discussed in Chapter 8 of WGI.

The GWP with a finite time horizon *T* was introduced by the IPCC (1990). With a 100-year time horizon, the GWP is used in the Kyoto Protocol and many other scientific and policy applications for converting emissions of various GHGs into "CO_2 equivalents". As pointed out in WGI, no scientific argument favors selecting 100 years compared with other choices. Conceptual shortcomings of the GWP include: (a) the choice of a finite time horizon is arbitrary, yet has strong effects on metric value (IPCC, 1990); (b) the same CO_2 equivalent amount of different gases may have different physical climate implications (Fuglestvedt, Berntsen, et al., 2000; O'Neill, 2000; Smith and Wigley, 2000); (c) physical impacts and impacts to humans (well-being) are missing; and (d) temporal aggregation of forcing does not capture important differences in temporal behavior. Limitations and inconsistencies also relate to the treatment of indirect effects and feedbacks (see WGI, Chapter 8).

Many alternative metrics have been proposed in the scientific literature. It can be argued that the net impacts from different gases should be compared (when measured in the same units) and the relative impact used for the exchange rate. The Global Damage Potential ('GDamP' in this Section) follows this approach by using climate damages as an impact proxy, and exponential discounting for inter-temporal aggregation of impacts (Hammitt et al., 1996b; Kandlikar, 1996b). Since marginal damages depend on the time at which GHGs are emitted, the GDamP is a time-variant metric. The GDamP accounts for the full causal chain from emissions to impacts. One advantage of the framework is that relevant normative judgements, such as the choice of inter-temporal discounting and the valuation of impacts, are explicit (Deuber et al., 2013). In practice, however, the GDamP is difficult to operationalize. The difficulties in calculating the GDamP and SCC are closely related (see Section 3.9.4).

The Global Cost Potential (GCP) calculates the time-varying ratio of marginal abatement costs of alternative gases arising in a cost-effective multi-gas mitigation strategy given a prescribed climate target (Manne and Richels, 2001), such as a cap on temperature change or on GHG concentrations. While the GCP avoids the problems associated with damage functions, it still requires complex integrated energy-economy-climate models to calculate GHG price ratios, and is therefore less transparent to stakeholders than physical metrics.[56]

The time-dependant Global Temperature Change Potential (GTP) is a physical metric that does not involve integration of the chosen impact parameter over time (Shine et al., 2007). It is defined as the relative effect of different gases on temperature at a predefined future date from a unit impulse of those gases. Typically these are normalized to a base, such as same mass of CO_2 emitted. While the GWP and GTP were not constructed with a specific policy target in mind, the GCP is conceptually more consistent with a policy approach aiming at achieving climate objectives in a cost-effective way (Fuglestvedt et al., 2003; Manning and Reisinger, 2011; Tol et al., 2012).

Virtually all metrics can be expressed in terms of a generalization of Equation 3.9.5 (Kandlikar, 1996b; Forster et al., 2007)

Equation 3.9.5. $$AM_j = \int_t I_{CO2}\left(\Delta T(t), RF(t), \ldots\right) W(t)\, dt,$$

Where the *impact function* I_j links the metric to the change in a physical climate parameter, typically the global mean radiative forcing *RF* (e.g., in the case of the GWP) or the change in global mean temperature ΔT (e.g., GTP and most formulations of the GDamP). In some cases, the impact function also considers the rate of change of a physical climate parameter (Manne and Richels, 2001; Johansson et al., 2006).

The temporal 'weighting function, W(t)', determines how the metric aggregates impacts over time. It can prescribe a finite time horizon (GWP), evaluation at a discrete point in time (GTP), or exponential

[56] In the context of a multi-gas integrated assessment model which seeks to minimize the cost of meeting a climate target.

discounting over an infinite time horizon (GDamP), which is consistent with the standard approach to inter-temporal aggregation used in economics (see Section 3.6.2). The weighting used in the GWP is a weight equal to one up to the time horizon and zero thereafter.

The categorization according to their choice of impact and temporal weighting function (Table 3.4) serves to expose underlying explicit and implicit assumptions, which, in turn, may reflect normative judgements. It also helps to identify relationships between different metric concepts (Tol et al., 2012; Deuber et al., 2013). In essence, the choice of an appropriate metric for policy applications involves a trade-off between completeness, simplicity, measurability and transparency (Fuglestvedt et al., 2003; Plattner et al., 2009; Deuber et al., 2013). The GDP and GCP are cost effective in implementing multi-gas mitigation policies, but are subject to large measurability, value-based and scientific uncertainties. Simple physical metrics, such as the GWP, are easier to calculate and produce a more transparent result, but are inaccurate in representing the relevant impact trade-offs between different GHGs (Fuglestvedt et al., 2003; Deuber et al., 2013).

The choice of metric can have a strong effect on the numerical value of GHG exchange rates. This is particularly relevant for CH_4, which operates on a much shorter timescale than CO_2. In WGI, Chapter 8.7, an exchange ratio of CH_4 to CO_2 of 28 is given for GWP and of 4 for a time horizon of 100 years for GTP.[57] For a quadratic damage function and a discount rate of 2%, Boucher (2012) obtained a median estimate of the GDamP exchange ratios of 24.3. This exchange rate obviously has very significant implications for relative emphasis a country may place on methane mitigation vs. carbon dioxide mitigation.

A small but increasing body of literature relates to the economic implications of metric choice. A limited number of model-based examinations find that, despite its conceptual short-comings, the GWP-100 performs roughly similarly to GTP or a cost-optimizing metric (such as the GCP) in terms of aggregate costs of reaching a prescribed climate target, although regional and sectoral differences may be significant (Godal and Fuglestvedt, 2002; Johansson et al., 2006; Reisinger et al., 2013; Smith et al., 2013; Ekholm et al., 2013). In other words, based on these few studies, the scope for reducing aggregate mitigation costs of reaching a particular climate target by switching to a metric other than the currently used GWP-100 may be limited, although there may be significant differences in terms of regional costs.

In the Kyoto Protocol, emission reductions of one GHG can be traded with reductions in all other GHGs. Such 'single-basket' approaches implicitly assume that the GHGs can linearly substitute each other in the mitigation effort. However, the same CO_2 equivalent amount of different GHGs can result in climate responses that are very different for transitional and long-term temperature change, chiefly due to different life-times of the substances (Fuglestvedt, Bernstsen, et al., 2000; Smith and Wigley, 2000). As an alternative, multi-basket approaches have been proposed, which only allow trading within groups of forcing agents with similar physical and chemical properties (Rypdal et al., 2005; Jackson, 2009; Daniel et al., 2012; Smith et al., 2013). Smith et al. (2013) propose a methodology for categorizing GHGs into two baskets of (a) long-lived species, for which the cumulative emissions determine the long-term temperature response, and (b) shorter-lived species for which sustained emissions matter. Applying separate emission equivalence metrics and regulations to each of the two baskets can effectively control the maximum peak temperature reached under a global climate policy regime. However, further research on the institutional requirements and economic implications of such an approach is needed, as it requires regulators to agree on separate caps for each basket and reduces the flexibility of emission trading systems to harvest the cheapest mitigation options.

[57] See WGI chapter 8, Appendix 8A for GWP and GTP values for an extensive list of components.

Table 3.4. Overview and classification of different metrics from the scientific literature

Name of metric		Impact function	Atmospheric background	Time dimension	Reference
GWP	Global Warming Potential	*RF*	Constant	Constant temporal weighting over fixed time horizon	IPCC (1990)
GWP-LA	Global Warming Potential (discounting)	*RF*	Constant, average of future conditions	Exponential discounting	Lashof and Ahuja (1990)
GTP-H	Global Temperature Change Potential (fixed time horizon)	ΔT	Constant	Evaluation at a fixed time T after emission	Fuglestvedt et al., (2010), Shine et al. (2005)
GTP(t)	Time-dependent global temperature change potential	ΔT	Time-varying	Evaluation at a fixed end point time in the future	Shine et al. (2007)
CETP	Cost Effective Temperature Potential	ΔT	Exogenous scenario	complex function of time when climate threshold is reached	Johannson (2012)
MGTP	Mean Global Temperature Change Potential	ΔT	Time-varying	Constant temporal weighting over fixed time horizon	Gillet and Mathews (2010), Peters et al (2011)
GCP	Global Cost Potential	Infinite damage above climate target	Time-varying	Exponential discounting	Manne and Richels (2001)
GDamP	Global Damage Potential	$D(\Delta T)$	Time-varying	Exponential discounting	Kandlikar (1996a), Hammit et al. (1996a)

3.10 Behavioural economics and culture

This Section summarizes behavioural economics related to climate change mitigation. We focus on systematic deviations from the traditional neoclassical economic model, which assumes that preferences are complete, consistent, transitive and non-altruistic, and that humans have unbounded computational capacity and rational expectations. In this context, social and cultural issues and conditions that frame our attitudes, as well as living conditions, are also addressed. Chapter 2 also considers behavioural questions, though primarily in the context of risk and uncertainty.

Although the focus is on the behaviour of individuals, some firms and organizations also take actions that appear to be inconsistent with the standard neoclassical model of the profit-maximizing firm (Lyon and Maxwell, 2007).

3.10.1 Behavioural economics and the cost of emissions reduction

Behavioural economics deals with cognitive limitations (and abilities) that affect people's economic decision-making processes. Choices can be affected and/or framed by perceived fairness, social norms, cooperation, selfishness and so on.[58] Behavioural economics emphasizes the cognitive, social

[58]See, e.g., Babcock and Loewenstein (1997), Shiv and Fedorikhin (1999), Asheim et al. (2006), Barrett (2007), Levati et al. (2007), Potters et al. (2007), Shogren and Taylor (2008) and Dannenberg et al. (2010).

and emotional factors that lead to apparently irrational choices. A growing number of documented systematic deviations from the neoclassical model help explain people's behaviour, but here we focus on several that we see as most relevant to climate change mitigation.[59]

3.10.1.1 Consumer undervaluation of energy costs

Consumers may undervalue energy costs when they purchase energy-using durables, such as vehicles, or make other investment decisions related to energy use.[60] By 'undervalue', we mean that consumers' choices systematically fail to maximize the utility they experience when the choices are implemented ('experienced' utility) (Kahneman and Sugden, 2005; see also, e.g., Fleurbaey, 2009). This misoptimization reduces demand for EE. Three potential mechanisms of undervaluation may be most influential (see also Box 3.10). First, when considering a choice with multiple attributes, evidence suggests that consumers are inattentive to add-on costs and ancillary attributes, such as shipping and handling charges or sales taxes (Hossain and Morgan, 2006; Chetty et al., 2009). It could be that EE is a similar type of ancillary product attribute and is thus less salient at the time of purchase. Second, significant evidence across many contexts also suggests that humans are 'present biased' (DellaVigna, 2009). If energy costs affect consumption in the future while purchase prices affect consumption in the present, this would lead consumers to be less energy efficient. Third, people's beliefs about the implications of different choices may be systematically biased (Jensen, 2010; Bollinger et al., 2011; Kling et al., 2012; McKenzie et al., 2013). Attari et al. (2010) show that people systematically underestimate the energy savings from a set of household energy conserving activities, and Allcott (2013) shows that the average consumer either correctly estimates or systematically slightly underestimates the financial savings from more fuel-efficient vehicles. Each of these three mechanisms of undervaluation appears plausible based on results from other contexts. However, rigorous evidence of misoptimization is limited in the specific context of energy demand (Allcott and Greenstone, 2012).

Three implications arise for climate and energy policy if the average consumer who is marginal to a policy does, in fact, undervalue energy costs. The first is an 'internality dividend' from carbon taxes (or other policies that internalize the carbon externality into energy prices): a carbon tax can actually increase consumer welfare when consumers undervalue energy costs (Allcott et al., forthcoming). This occurs because undervaluation would be a pre-existing distortion that reduces demand for EE below consumers' private optima, and one that increasing carbon taxes helps to correct. Second, in addition to carbon taxes, other tax or subsidy policies that raise the relative purchase price of energy-inefficient durable goods can improve welfare (Cropper and Laibson, 1999; O'Donoghue and Rabin, 2008; Fullerton et al., 2011). Third, welfare gains are largest from policies that preferentially target consumers who undervalue energy costs the most. This effect is related to the broader philosophies of libertarian paternalism (Sunstein and Thaler, 2003) and asymmetric paternalism (Camerer et al., 2003), which advocate policies that do not infringe on freedom of choice but could improve choices by the subset of people who misoptimize. In the context of energy demand, such policies might include labels or programmes that provide information about, and attract attention to, energy use by durable goods.

3.10.1.2 Firm behaviour

Some of the phenomena described above may also apply to firms. Lyon and Maxwell (2004, 2008) examine in detail the tendency of firms to undertake pro-environment actions, such as mitigation, without being prompted by regulation. Taking a neoclassical approach to the problem, they find that

[59] See Rachlinksi (2000), Brekke and Johansson-Stenmann (2008), Gowdy (2008) and the American Psychological Association (2010).

[60] This can even apply to cases that use sophisticated methods to support decisions (e.g., Korpi and Ala-Risku, 2008).

firms view a variety of pro-environment actions as being to their advantage. However, evidence of a compliance norm has been found in other contexts where firms' responses to regulation have been studied (Ayres and Braithwaite, 1992; Gunningham et al., 2003).

The conventional economic model represents the firm as a single, unitary decision-maker, with a single objective, namely, profit maximization. As an alternative to this 'black-box' model of the firm (Malloy, 2002), the firm may be seen as an organization with a multiplicity of actors, perhaps with different goals, and with certain distinctive internal features (Coase, 1937; Cyert and March, 1963; Williamson, 1975).

3.10.1.3 Non-price interventions to induce behavioural change

Besides carbon taxes and other policies that affect relative prices, other non-price policy instruments can reduce energy demand, and, therefore, carbon emissions. Such interventions include, supplying information on potential savings from energy-efficient investment, drawing attention to energy use, and providing concrete examples of energy-saving measures and activities (e.g., Stern, 1992; Abrahamse et al., 2005). They also include providing feedback on historical energy consumption (Fischer, 2008) and information on how personal energy use compares to a social norm (Allcott, 2011).[61]

In some cases, non-price energy conservation and efficiency programmes may have low costs to the programme operator, and it is therefore argued that they are potential substitutes if carbon taxes are not politically feasible (Gupta et al., 2007). However, it is questionable whether such interventions are appropriate substitutes for carbon taxes, for example, in terms of environmental and cost effectiveness, because their impact may be small (Gillingham et al., 2006) and unaccounted costs may reduce the true welfare gains. For example, consumers' expenditures on energy-efficient technologies and time spent turning lights off may not be observed.

Research in other domains (e.g., Bertrand et al., 2010) has shown that a person's choices are sometimes not consistent. They may be malleable by 'ancillary conditions' – non-informational factors that do not affect experienced utility. In the context of EE, this could imply that energy demand may be reduced with relatively low welfare costs through publicity aimed at changing consumer preferences. However, publicly-funded persuasion campaigns bring up important ethical and political concerns, and the effectiveness of awareness-raising programmes on energy and carbon will depend on how consumers actually use the information and the mix of policy instruments (Gillingham et al., 2006; Gupta et al., 2007; also Worrell et al., 2004; Mundaca et al., 2010).

3.10.1.4 Altruistic reductions of carbon emissions

In many contexts, people are altruistic, being willing to reduce their own welfare to increase that of others. For example, in laboratory 'dictator games', people voluntarily give money to others (Forsythe et al., 1994), and participants in public goods games regularly contribute more than the privately-optimal amount (Dawes and Thaler, 1988; Ledyard, 1993) . Charitable donations in the United States amount to more than 2% of GDP (List, 2011). Similarly, many individuals voluntarily contribute to environmental public goods, such as reduced carbon emissions. For example, $387 million were spent on voluntary carbon offset purchases in 2009 (Bloomberg, 2010).

Pre-existing altruistic voluntary carbon emission reductions could moderate the effects of a new carbon tax on energy demand because the introduction of monetary incentives can 'crowd out' altruistic motivations (Titmuss, 1970; Frey and Oberholzer-Gee, 1997; Gneezy and Rustichini, 2000). Thus, a carbon tax could reduce voluntary carbon emission reductions even as it increases

[61] The efficacy of these interventions can often be explained within neoclassical economic models. From an expositional perspective, it is still relevant to cover them in this Subsection.

financially-motivated ones. While this effect might not weaken the welfare argument for a carbon tax, it does reduce the elasticity of carbon emissions to a carbon tax.

Reciprocity, understood as the practice of people rewarding generosity and castigating cruelty towards them, has been found to be a key driver of voluntary contributions to public goods. Positive reciprocity comes in the form of conditional cooperation, which is a tendency to cooperate when others do so too (Axelrod, 1984; Fischbacher et al., 2001; Frey and Meier, 2004). However, cooperation based on positive reciprocity is often fragile and is declining over time (Bolton et al., 2004; Fischbacher and Gächter, 2010). Incentives and penalties are fundamental to maintaining cooperation in environmental treaties (Barrett, 2003). Adding a strategic option to punish defectors often stabilizes cooperation, even when punishment comes at a cost to punishers (Ostrom et al., 1992; Fehr and Gächter, 2002). Yet, if agents are allowed to counter-punish, the effectiveness of reciprocity to promote cooperation might be mitigated (Nikiforakis, 2008). However, most laboratory studies have been conducted under symmetric conditions and little is known about human cooperation in asymmetric settings, which tend to impose more serious normative conflicts (Nikiforakis et al., 2012).

Experiments also reveal a paradox: actors can agree to a combined negotiated climate goal for reducing the risk of catastrophe, but behave as if they were blind to the risks (Barrett and Dannenberg, 2012). People are also often motivated by concerns about the fairness of outcomes and procedures; in particular, many do not like falling behind others (Fehr and Schmidt, 1999; Bolton and Ockenfels, 2000; Charness and Rabin, 2002; Bolton et al., 2005). Such concerns can both promote and hamper the effectiveness of negotiations, including climate negotiations, in overcoming cooperation and distributional problems (Güth et al., 1982; Lange and Vogt, 2003; Lange et al., 2007; Dannenberg et al., 2010).

Uncertainty about outcomes and behaviours also tends to hamper cooperation (Gangadharan and Nemes, 2009; Ambrus and Greiner, 2012). As a result, the information given to, and exchanged by, decision makers may affect social comparison processes and reciprocal interaction, and thus the effectiveness of mechanisms to resolve conflicts (Goldstein et al., 2008; Chen et al., 2010; Bolton et al., 2013). In particular, face-to-face communication has been proved to significantly promote cooperation (Ostrom, 1990; Brosig et al., 2003) . Concerns about free-riding are perceived as a barrier to engaging in mitigation actions (Lorenzoni et al., 2007). The importance of fairness in promoting international cooperation (see also Chapter 4) is one of the few non-normative justifications for fairness in climate policy.

3.10.1.5 Human ability to understand climate change

So far, we have covered deviations from the neoclassical model that affect energy demand. Such deviations can also affect the policy-making process. The understanding of climate change as a physical phenomenon with links to societal causes and impacts is highly complex (Weber and Stern, 2011). Some deviations are behavioural and affect perceptions and decision making in various settings besides climate change. (See Section 2.2 for a fuller discussion). For example, perceptions of, and reactions to, uncertainty and risk can depend not only on external reality, as assumed in the neoclassical model, but also on cognitive and emotional processes (Subsection 2.2.1). When making decisions, people tend to overweight outcomes that are especially 'available' or salient (Kahneman and Tversky, 1974, 1979). They are more averse to losses than they are interested in gains relative to a reference point (Kahneman and Tversky, 1979). Because climate change involves a loss of existing environmental amenities, this can increase its perceived costs. However, if the costs of abatement are seen as a reduction relative to a reference rate of future economic growth, this can increase the perceived costs of climate change mitigation.

Some factors make it hard for people to think about climate change and lead them to underweight it: it happens gradually; the major effects are likely to occur in the distant future; the effects will be felt elsewhere; and their nature is uncertain. Furthermore, weather is naturally variable, and the distinction between weather and climate is often misunderstood (Reynolds et al., 2010). People's perceptions and understanding of climate change do not necessarily correspond to scientific knowledge (Subsection 2.2.1.1) because they are more vulnerable to emotions, values, views and (unreliable) sources (Weber and Stern, 2011). People are likely to be misled if they apply their conventional modes of understanding to climate change (Bostrom et al., 1994).

3.10.2 Social and cultural issues

In recent years, the orientation of social processes and norms towards mitigation efforts has been seen as an alternative or complement to traditional mitigation actions, such as incentives and regulation. We address some of the concepts discussed in the literature which, from a social and cultural perspective, contribute to strengthening climate change actions and policies.

3.10.2.1 Customs

In both developed and developing countries, governments, social organizations and individuals have tried to change cultural attitudes towards emissions, energy use and, lifestyles (European Commission, 2009). For example, household energy-use patterns for space and water heating differ significantly between Japan and Norway because of lifestyle differences (Wilhite et al., 1996; Gram-Hanssen, 2010). Some have argued that the bio-cultural heritage of indigenous peoples is a resource that should be valued and preserved as it constitutes an irreplaceable bundle of teachings on the practices of mitigation and sustainability (Sheridan and Longboat, 2006; Russell-Smith et al., 2009; Kronik and Verner, 2010). Sometimes local strategies and indices have metamorphosed into national policies, as in the case of 'Buen Vivir' in Ecuador (Choquehuanca, 2010; Gudynas, 2011) and 'Gross National Happiness' (GNH), described in Box 3.11. In rich countries, and among social groups with high levels of environmental awareness, interest in sustainability has given rise to cultural movements promoting change in modes of thought, production, and consumption. Including the cultural dimension in mitigation policies facilitates social acceptability.

Box 3.11 Gross National Happiness (GNH)

The Kingdom of Bhutan has adopted an index of GNH as a tool for assessing national welfare and planning development (Kingdom of Bhutan, 2008). According to this concept, happiness does not derive from consumption, but rather from factors such as the ability to live in harmony with nature (Taplin et al., 2013). Thus, GNH is both a critique of, and an alternative to, the conventional global development model (Taplin et al., 2013). The GNH Index measures wellbeing and progress according to nine key domains (and 72 core indicators) (Uddin et al., 2007). The intention is to increase access to health, education, clean water and electrical power (Pennock and Ura, 2011) while maintaining a balance between economic growth, environmental protection and the preservation of local culture and traditions. This is seen as a 'Middle Way' aimed at tempering the environmental and social costs of unchecked economic development (Frame, 2005; Taplin et al., 2013).

3.10.2.2 Indigenous peoples

Indigenous peoples number millions across the globe (Daes, 1996). Land and the natural environment are integral to their sense of identity and belonging and to their culture, and are essential for their survival (Gilbert, 2006; Xanthaki, 2007). The ancestral lands of indigenous peoples contain 80% of the earth's remaining healthy ecosystems and global biodiversity priority areas, including the largest tropical forests (Sobrevila, 2008). Because they depend on natural resources and inhabit biodiversity-rich but fragile ecosystems, indigenous peoples are particularly vulnerable to climate change and have only limited means of coping with such change (Henriksen, 2007; Permanent Forum on Indigenous Issues, 2008). They are often marginalized in decision-making and unable to participate adequately in local, national, regional and international climate-change mechanisms. Yet, it is increasingly being recognized that indigenous peoples can impart valuable insights into ways of managing mitigation and adaptation (Nakashima et al., 2012), including forest governance and conserving ecosystems (Nepstad et al., 2006; Hayes and Murtinho, 2008; Persha et al., 2011).

3.10.2.3 Women and Climate Change

Women often have more restricted access to, and control of, the resources on which they depend than men. In many developing countries, most small-scale food producers are women. They are usually the ones responsible for collecting water and fuel and for looking after the sick. If climate change adversely affects crop production and the availability of fuel and water, or increases ill health, women may bear a disproportionate burden of those consequences (Dankelman, 2002; UNEP, 2011).[62] On the other hand, they may be better at adapting to climate change, both at home and in the community. But given their traditional vulnerability, the role of women across society will need to be re-examined in a gender-sensitive manner to ensure they have equal access to all types of resources (Agostino and Lizarde, 2012).

3.10.2.4 Social institutions for collective action

Social institutions shape individual actions in ways that can help in both climate mitigation and adaptation. They promote trust and reciprocity, establish networks, and contribute to the evolution of common rules. They also provide structures through which individuals can share information and knowledge, motivate and coordinate behaviour, and act collectively to deal with common challenges. Collective action is reinforced when social actors understand they can participate in local solutions to a global problem that directly concerns them.

As noted in Subsections 3.10.1.5 and 2.2, public perceptions of the cause and effect of climate change vary, in both developed and developing countries, with some erroneous ideas persisting even among well-educated people. Studies of perceptions (O'Connor et al., 1999; Corner et al., 2012) demonstrate that the public is often unaware of the roles that individuals and society can play in both mitigation and adaptation. The concepts of social and policy learning can be used in stimulating and organizing collective action. Social learning involves participation by members of a group in discourse, imitation and shared collective or individual actions. The concept of policy learning describes the process of adaptation by organizations to external change while retaining or strengthening their own objectives and domination over existing socio-economic structures (Adger and Kelly, 1999). The task of an educational programme in mitigating and adapting to climate change is to represent a collective global problem in individual and social terms. This will require the strategies for disseminating scientific information to be reinforced and the practical implications advertised in ways that are understandable to diverse populations (González Gaudiano and Meira Cartea, 2009).

3.11 Technological change

Mitigation scenarios aim at significant reductions in current emission levels that will be both difficult and costly to achieve with existing technological options. However, cost-reducing technological innovations are plausible. The global externality caused by climate change compounds market failures common to private sector innovations. Appropriate policy interventions are accordingly needed to encourage the type and amount of climate-friendly technological change (TC) that would lead to sizable reductions in the costs of reducing carbon emissions. This Section reviews theories, concepts and principles used in the study of environmentally-oriented TC, and highlights key lessons from the literature, in particular, the potential of policy to encourage TC. Examples of success and

[62] Natural disasters over the period 1981–2002 revealed evidence of a gender gap: natural disasters lowered women's life expectancy more than men's: the worse the disaster and the lower the woman's socio-economic status the bigger the disparity (Neumayer and Plümper, 2007).

failure in promoting low carbon energy production and consumption technologies are further evaluated in Chapters 6-16.

3.11.1 Market provision of TC

As pollution is not fully priced by the market, private individuals lack incentives to invest in the development and use of emissions-reducing technologies in the absence of appropriate policy interventions. Market failures other than environmental pollution include what is known as the 'appropriability problem'. This occurs when inventors copy and build on existing innovations, and reap part of the social returns on them. While the negative climate change externality leads to over use of the environment, the positive 'appropriability' externality leads to an under-supply of technological innovation.[63] Indeed, empirical research provides ample evidence that social rates of return on R&D are higher than private rates of return (Griliches, 1992). Thus, the benefits of new knowledge may be considered as a public good (see, e.g., Geroski, 1995).

Imperfections in capital markets often distort the structure of incentives for financing technological development. Information about the potential of a new technology may be asymmetrically held, creating adverse selection (Hall and Lerner, 2010). This may be particularly acute in developing countries. The issue of path dependence, acknowledged in evolutionary models of TC, points to the importance of transformative events in generating or diverting technological trajectories (see Chapters 4 and 5). Even endogenously induced transformative events may not follow a smooth or predictable path in responding to changing economic incentives, suggesting that carbon-price policy alone may not promote the desired transformative events.

3.11.2 Induced innovation

The concept of 'induced innovation' postulates that investment in R&D is profit-motivated and responds positively to changes in relative prices[64] (Hicks, 1932; Binswanger and Ruttan, 1978; Acemoglu, 2002).[65] Initial evidence of induced TC focused on the links between energy prices and innovation and revealed the lag between induced responses and the time when price changes came into effect, which is estimated at five years by Newell et al. (1999) and Popp (2002) (see Chapter 5). Policy also plays an important role in inducing innovation, as demonstrated by the increase in applications for renewable energy patents within the European Union in response to incentives for innovation provided by both national policies and international efforts to combat climate change (Johnstone et al., 2010) . Recent evidence also suggests that international environmental agreements provide policy signals that encourage both innovation (Dekker et al., 2012) and diffusion (Popp et al., 2011). With the exception of China, most climate-friendly innovation occurred in developed countries (Dechezlepretre et al., 2011).[66]

3.11.3 Learning-by-doing and other structural models of TC

An extensive literature relates to rates of energy cost reduction based on the concept of 'experience' curves (see Chapter 6). In economics, this concept is often described as learning-by-doing (LBD) – to

[63] For incremental innovations, the net technology externality can be negative. Depending on market structure and intellectual property rules, the inventor of an incremental improvement on an existing technology may be able to appropriate the entire market, thereby earning profits that exceed the incremental value of the improvement.

[64] It should be pointed out that in economics, '"induced innovation'" typically means innovation induced by relative price differences. The IPCC uses a different definition: innovation induced by policy.

[65] In economics, 'induced innovation' typically means innovation induced by relative price differences. The IPCC uses a different definition: innovation induced by policy.

[66] Global R&D expenditures amounted to $1.107 trillion in 2007, with OECD nations accounting for 80%, and the U.S. and Japan together accounting for 46% (National Science Board, 2010).

describe the decrease in costs to manufacturers as a function of cumulative output – or 'learning-by-using', reflecting the reduction in costs (and/or increase in benefits) to consumers as a function using a technology. While learning curves are relatively easy to incorporate into most climate integrated assessment models (IAMs), the application of LBD has limitations as a model of TC (Ferioli et al., 2009) . Learning curves ignore potential physical constraints. For example, while costs may initially fall as cumulative output expands, if renewable energy is scaled up, the use of suboptimal locations for production would increase costs. Ferioli et al. (2009) also provide evidence that learning can be specific to individual components, so that the savings from learning may not fully transfer from one generation of equipment to the next. They therefore suggest caution when extrapolating cost savings from learning curves to long-term frames or large-scale expansions. Similarly, in a study on cost reductions associated with photovoltaic cells, Nemet (2006) finds that most efficiency gains come from universities, which have little traditional LBD through production experience. Hendry and Harborne (2011) provide examples of the interaction of experience and R&D in the development of wind technology.

3.11.4 Endogenous and exogenous TC and growth

Within climate policy models, TC is either treated as exogenous or endogenous. Köhler et al. (2006), Gillingham et al. (2008) and Popp et al. (2010) provide reviews of the literature on TC in climate models.

Exogenous TC (most common in models) progresses at a steady rate over time, independently of changes in market incentives. One drawback of exogenous TC is that it ignores potential feedback between climate policy and the development of new technologies. Models with endogenous TC address this limitation by relating technological improvements in the energy sector to changes in energy prices and policy. These models demonstrate that ignoring induced innovation overstates the costs of climate control.

The Nordhaus (1977, 1994) DICE model is the pioneering example of a climate policy model incorporating TC into IAMs. In most implementations of DICE, TC is exogenous. Efforts to endogenize TC have been difficult, mainly because market-based spillovers from R&D are not taken into account when deciding how much R&D to undertake. Recent attempts to endogenize TC include WITCH model (Bosetti et al., 2006)and Popp's (2004) ENTICE model. Popp (2004) shows that models that ignore directed TC do indeed significantly overstate the costs of environmental regulation (more detailed discussion on TC in these and more recent models is provided in Chapter 6).

An alternative approach builds on new growth theories, where TC is by its nature endogenous, in order to look at the interactions between growth and the environment. Policies like R&D subsidies or carbon taxes affect aggregate growth by affecting entrepreneurs' incentives to innovate. Factoring in firms' innovations dramatically changes our view of the relationship between growth and the environment. More recent work by Acemoglu et al. (2012) extends the endogenous growth literature to the case where firms can choose the direction of innovation (i.e., they can decide whether to innovate in more or less carbon-intensive technologies or sectors).[67]

In contrast, LBD models use learning curve estimates to simulate falling costs for alternative energy technologies as cumulative experience with the technology increases. One criticism of these models is that learning curve estimates provide evidence of correlation, but not causation. While LBD is easy to implement, it is difficult to identify the mechanisms through which learning occurs. Goulder and Mathai (2000) provide a theoretical model that explores the implications of modelling technological

[67] Other works investigating the response of technology to environment regulations include Grübler and Messner (1998), Manne and Richels (2004b), Messner (1997), Buonanno et al. (2003), Nordhaus (2002), Di Maria and Valente (2008), Bosetti et al. (2008), Massetti et al. (2009), Grimaud and Rouge (2008), and Aghion et al. (2009).

change through R&D or LBD (several empirical studies on this are reviewed in more detail in Chapter 6).

3.11.5 Policy measures for inducing R&D

Correcting the environmental externality or correcting knowledge market failures present two key options for policy intervention to encourage development of climate-friendly technologies. Patent protection, R&D tax credits and rewarding innovation are good examples of correcting failures in knowledge markets and promoting higher rates of innovation. On the other hand, policies regulating environmental externalities, such as a carbon tax or a cap-and-trade system, influence the direction of innovation.

Chapter 15 discusses in more detail how environmental and technology policies work best in tandem (e.g. Popp, 2006; Fischer, 2008; Acemoglu et al., 2012). For instance, in evaluating a broad set of policies to reduce CO_2 emissions and promote innovation and diffusion of renewable energy in the United States electricity sector, Fischer & Newell (2008) find that a portfolio of policies (including emission pricing and R&D) achieves emission reductions at significantly lower cost than any single policy (see Chapters 7 to 13). However, Gerlagh and van der Zwaan (2006) note the importance of evaluating the trade-off between cost savings from innovation and Fischer and Newell (2008) assumptions of decreasing returns to scale due to space limitations for new solar and wind installations.

3.11.6 Technology transfer (TT)

Technology transfer (TT) has been at the centre of the scholarly debate on climate change and equity in economic development as a way for developed countries to assist developing countries access new low carbon technologies. Modes of TT include, trade in products, knowledge and technology, direct foreign investment, and international movement of people (Hoekman et al., 2005). Phases and steps for TT involve absorption and learning, adaptation to the local environment and needs, assimilation of subsequent improvements, and generalization. Technological learning or catch-up thus proceeds in stages: importing foreign technologies; local diffusion and incremental improvements in process and product design; and marketing, with different policy measures suited to different stages of the catch-up process.

'Leapfrogging', or the skipping of some generations of technology or stages of development, is a useful concept in the climate change mitigation literature for enabling developing countries to avoid the more emissions-intensive stages of development (Watson and Sauter, 2011). Examples of successful low-carbon leapfrogging are discussed in more detail in Chapter 14.

Whether proprietary rights affect transfers of climate technologies has become a subject of significant debate. Some technologies are in the public domain; they are not patented or their patents have expired. Much of the debate on patented technologies centres on whether the temporary monopoly conferred by patents has hampered access to technology. Proponents of strong intellectual property (IP) rights believe that patents enhance TT as applicants have to disclose information on their inventions. Some climate technology sectors, for example, those producing renewable energy, have easily available substitutes and sufficient competition, so that patents on these technologies do not make them costly or prevent their spread (Barton, 2007). In other climate-related technology sectors, IP protection could be a barrier to TT (Lewis, 2007). (The subject is further discussed in Chapters 13 and 15.)

Various international agreements on climate change, trade and intellectual property include provisions for facilitating the transfer of technology to developing countries. Climate change agreements encourage participation by developing countries and address barriers to the adoption of technologies, including financing. However, some scholars have found these agreements to be ineffective because they do not incorporate mechanisms for ensuring technology transfers to developing countries (Moon, 2008). (The literature on international cooperation on TT is further discussed in Chapters 13, 14 and 16.)

3.12 Gaps in knowledge and data

As this Chapter makes clear, many questions are not completely answered by the literature. So it is prudent to end our assessment with our findings on where research might be directed over the coming decade so that the AR6 (should there be one) may be able to say more about the ethics and economics of climate change.

- To plan an appropriate response to climate change, it is important to evaluate each of the alternative responses that are available. How can we take into account changes in the world's population? Should society aim to promote the total of people's wellbeing in the world, or their average wellbeing, or something else? The answer to this question will make a great difference to the conclusions we reach.
- The economics and ethics of geoengineering is an emerging field that could become of the utmost importance to policymakers. Deeper analysis of the ethics of this topic is needed, as well as more research on the economic aspects of different possible geoengineering approaches and their potential effects and side effects.
- To develop better and more realistic estimates of the components of the damage function, more closely connected to WGII assessments of physical impacts. Quantifying non-market values, that is, measuring valuations placed by humans on nature and culture, is highly uncertain and could be improved through more and better methods and empirical studies. As discussed in Section 3.9 , the aggregate damage functions used in many IAMs are generated from a remarkable paucity of data and are thus of low reliability.
- Ex-post evaluation addressing the effectiveness of different regulatory approaches, both singly and jointly can be invaluable. For instance, understanding, retrospectively, the effectiveness of the European Union Emissions Trading Scheme (EU ETS), the California cap-and-trade system, or the interplay between renewable standards and carbon regulations in a variety of countries.
- Energy models need to provide a more realistic portrait of microeconomic decision-making frameworks for technology-choice (energy-economy models).
- A literature is emerging in economics and ethics on the risk of catastrophic climate change impacts, but much more probing into the ethical dimensions is needed to inform future economic analysis.
- More research that incorporates behavioural economics into climate change mitigation is needed. For instance, more work on understanding how individuals and their social preferences respond to (ambitious) policy instruments and make decisions relevant to climate change is critical.
- To improve understanding of mitigation costs. Despite the importance of the cost of mitigation, the aggregate cost of mitigating x tonnes of carbon globally is poorly understood. To put it differently, a global carbon tax of x dollars per tonne would yield y(t) tonnes of carbon abatement at time, t. We do not understand the relationship between x and y(t).
- To evaluate climate risk. The choice of the rate at which future uncertain climate damages are discounted depends on their risk profile in relation to other risks in the economy. By how much does mitigating climate change reduce the aggregate uncertainty faced by future generations?

- To improve Integrated Assessment Models. As has been recently underscored by several authors (Pindyck, 2013; Stern, 2013) as well as this review, integrated assessment models have very significant shortcomings for CBA, as they do not fully represent climate damages, yet remain important tools for investigating climate policy. They have been widely and successfully applied for CEA analysis (Paltsev et al., 2008; Clarke et al., 2009; Krey and Clarke, 2011; Fawcett et al., 2013). Research into improving the state-of-the-art of such models (beyond just updating) can have high payoff.

3.13 Frequently Asked Questions

FAQ 3.1 The IPCC is charged with providing the world with a clear scientific view of the current state of knowledge on climate change. Why does it need to consider ethics?

The IPCC aims to provide information that can be used by governments and other agents when they are considering what they should do about climate change. The question of what they should do is a normative one and thus has ethical dimensions because it generally involves the conflicting interests of different people. The answer rests implicitly or explicitly on ethical judgements. For instance, an answer may depend on a judgement about the responsibility of the present generation towards people who will live in the future or on a judgement about how this responsibility should be distributed among different groups in the present generation. The methods of ethical theory investigate the basis and logic of judgements such as these.

FAQ 3.2 Do the terms justice, fairness and equity mean the same thing?

The terms ‘justice’, ‘fairness’ and ‘equity’ are used with subtly different meanings in different disciplines and by different authors. ‘Justice’ and ‘equity’ commonly have much the same meaning: ‘justice’ is used more frequently in philosophy; ‘equity’ in social science. Many authors use ‘fairness’ as also synonymous with these two. In reporting on the literature, the IPCC assessment does not impose a strictly uniform usage on these terms. All three are often used synonymously. Section 3.3 describes what they refer to, generally using the term ‘justice’.

Whereas justice is broadly concerned with a person receiving her due, ‘fairness’ is sometimes used in the narrower sense of receiving one’s due (or ‘fair share’) in comparison with what others receive. So it is unfair if people do not all accept an appropriate share of the burden of reducing emissions, whereas on this narrow interpretation it is not unfair – though it may be unjust – for one person’s emissions to harm another person. Fairness is concerned with the distribution of goods and harms among people. ‘Distributive justice’ – described in Section 3.3 – falls under fairness on the narrow interpretation.

FAQ 3.3 What factors are relevant in considering responsibility for future measures that would mitigate climate change?

It is difficult to indicate unambiguously how much responsibility different parties should take for mitigating future emissions. Income and capacity are relevant, as are ethical perceptions of rights and justice. One might also investigate how similar issues have been dealt with in the past in non-climate contexts. Under both common law and civil law systems, those responsible for harmful actions can only be held liable if their actions infringe a legal standard, such as negligence or nuisance. Negligence is based on the standard of the reasonable person. On the other hand, liability for causing a nuisance does not exist if the actor did not know or have reason to know the effects of its conduct. If it were established that the emission of GHGs constituted wrongful conduct within the terms of the law, the nature of the causal link to the resulting harm would then have to be demonstrated.

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